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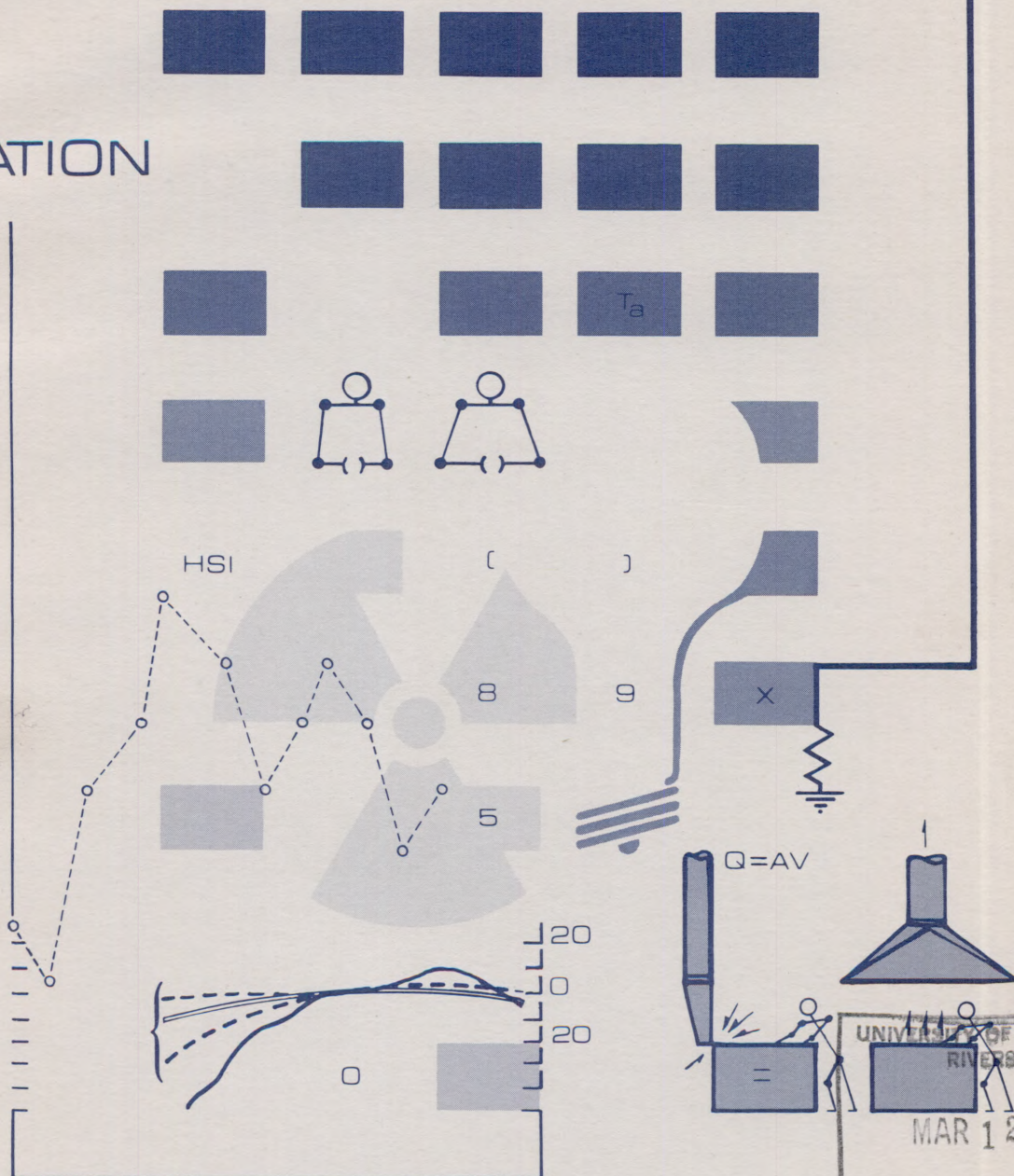


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552

INDUSTRIAL HYGIENE ENGINEERING & CONTROL

RADIATION



Instructor
Manual

U.S. DEPARTMENT OF HEALTH, EDUCATION AND WELFARE
Public Health Service
Center for Disease Control
National Institute for Occupational Safety and Health

Division of Training and Manpower Development

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INTRODUCTION TO INDUSTRIAL HYGIENE ENGINEERING AND CONTROL (552)

This is a modularized course designed for use as a one, two, or three week short course or as a one or two semester academic course at either the undergraduate or graduate level. It examines the fundamentals for design of controls to eliminate or satisfactorily deal with occupational health hazards. Lectures, augmented by problem solving sessions, are intended to assist the trainee in selecting, designing, and applying control methods in the work environment. Primary attention is given to industrial ventilation, noise and vibration control, heat stress, and industrial illumination as well as new engineering topics.

The training course manual has been specially prepared for the trainees attending the course and should not be included in reading lists of periodicals as generally available.

Module 6 — Instructor's Manual

NONIONIZING AND IONIZING RADIATION

Division of Training and Manpower Development

National Institute for Occupational Safety and Health

**U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Center for Disease Control**

Cincinnati, Ohio

November 1978

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FOREWORD

The material presented in this document is designed for use in a college or university classroom and is directed to students at an advanced level of study in industrial hygiene. The course may also be utilized in total or in part as the basis for short course offerings.

This material was developed under sponsorship of the National Institute for Occupational Safety and Health, Division of Training and Manpower Development, Cincinnati, Ohio, (Contract CDC-210-75-0076). Serving as Project Officer for the development of this material was Robert B. Weidner, J.D., Branch Chief, Division of Training and Manpower Development.

The lesson plans and accompanying text entitled *Industrial Hygiene Engineering and Control* were prepared by the staff of Management Resource Associates, Monroeville, Pennsylvania. Serving as authors were Bruce B. Byers, Ronald J. Hritz, and James C. McClintock. Also assisting, as consultants to the development of the materials, were Ralph J. Vernon, Ph.D., and Richard B. Konzen, Ph.D., of Texas A&M University.

Art work for the text was prepared by Carole D. Byers. Manuscript preparation was the responsibility of Elaine S. Holmes.

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INTRODUCTION

Purpose of the Course

The course materials are designed for presentation to students at the baccalaureate or graduate level of study in Industrial Hygiene. The materials presuppose that the student has completed introductory courses in recognition, measurement, and evaluation of occupational health hazards. The materials are designed in such a manner that they are applicable as a two-semester course or a three-week intensive study short course. In addition, the materials may be divided to provide courses of a shorter duration. Since the course is divided into self-contained modules, each module can be used as the basis for the development of a course. (e.g., Module 2, Industrial Ventilation can be utilized as a one-semester offering or a one-week short course.)

The emphasis in each module is the control of occupational hazards. However, this emphasis does not preclude the inclusion of recognition, measurement and evaluation topics within the module. Summary material covering these important areas is included where appropriate within each module. This inclusion is based upon the authors' belief that problem identification and definition are important steps that must be taken before adequate control can be implemented.

Content

The materials are divided into eight (8) self-contained modules. Each module is divided into units and lessons. For the most part, the lessons are based upon a one-hour class session for presentation. The modules that are included, as well as the *minimum* time available to cover the modules are:

<i>Module</i>	<i>Title</i>	<i>Minimum Time</i>
1	Introduction to Industrial Hygiene Engineering and Control	7 Hours
2	Industrial Ventilation	31 Hours
3	Thermal Stress	4 Hours
4	Sound	7 Hours
5	Industrial Illumination	3 Hours
6	Nonionizing and Ionizing Radiation	8 Hours
7	Ergonomics	5 Hours
8	Other Topics	7 Hours
		Total Time <u>72 Hours</u>

The time allotted is a minimum time that does not include allowance for testing and review of problems and exercises. Based upon the experience gained in a pilot test of the materials, the time allotted above provides for only a brief coverage of the topics included. For thorough coverage of each subject, the allotted time should be increased to at least 120 hours. In any case, the time required is dependent upon the level of detail and completeness of coverage of each topic that is desired.

Course Prerequisites

The students should have taken courses in recognition, measurement and evaluation of occupational health hazards. At a minimum, the students should have completed the following NIOSH sponsored courses or their equivalent:

- Recognition, Evaluation and Control of Occupational Hazards
- Industrial Hygiene Measurements

In addition, the students should have completed education in undergraduate mathematics through the calculus and undergraduate science including general and organic chemistry, physics, and biology. Additional engineering courses such as fluid mechanics and thermodynamics will be helpful to the student.

Components of the Course

The Course Manual is designed to provide the technically competent instructor with the basic educational materials from which to conduct the training sessions. It is not the purpose of the Course Manual to provide a complete skill and knowledge package from which the instructor can obtain the technical competency necessary to conduct training, since such competence is assumed to be an attribute of any instructor chosen to teach in the program. Should the instructor wish to brush up on certain skills and knowledge, the references cited as well as the accompanying text, *Industrial Hygiene Engineering and Control*, will provide a basis for this undertaking.

The course is organized with three (3) basic elements. These elements are:

1. Module—A complete, self-contained package of educational materials that is directed toward the attainment of skills and knowledge in a subject area. These modules can be presented as a stand-alone course or can be combined in various ways to construct courses for use with selected groups of students.
2. Unit—A self-contained package of educational materials that is directed toward attainment of a subset of skills and knowledge in a subject area. The unit does not necessarily lend itself to use as a stand-alone package since certain segments of the skills and knowledge presented depend upon completing previous units within the module.
3. Lesson—Generally, an artificial segmentation of a unit for administrative purposes. Lesson segments are normally one hour in length and, as far as is practical, cover a logical subset of knowledge or skills. Lessons allow for the scheduling of the training in various educational environments.

Instructor's Manual—The Module Plan

The module plan contains the following components:

1. Unit and Lesson Topic Outlines—This outline presents the topics covered within the module and the schedule for presentation of these topics. This information provides a concise and organized summary of the subject material in the module.
2. Terminal Objectives—General competency statements related to the skills and knowledge that should be possessed by the student upon completion of

the module. The skill objectives relate to the manipulative, computational, or decision-making skills that the student should attain upon completion of the module. The knowledge objectives relate to the subject knowledge that the student requires in order to perform the required skills. These objectives serve as a basis upon which an evaluation can be made of the student's mastery of the subject material included in the module.

3. Self-Tests—Postmodule self-tests along with the correct answers to these tests are included with each module.
4. References—A list of reference material can be consulted by the instructor or students.

Instructor's Manual—The Unit Plan

The unit is made up of a number of specific components and contains the lesson content outline. The components of the unit plan are:

1. Performance Objectives—Skill and knowledge objectives related to the subject matter included within the unit. These objectives are written in behavioral terms (i.e., an observable activity or result that can be evaluated quantitatively, as specified, and which is conducted or obtained under specific conditions). The objectives that are presented within the unit plan are of a more specific nature than those terminal objectives or competency statements that are specified by the module plan. The performance objectives presented within the unit might be thought of as enabling objectives; i.e., they represent the skills and knowledge that the student must attain in order to complete the requirements of the terminal objectives for the module.
2. Unit Activities—Activities that the student must perform to complete the unit. Reading assignments, reference materials, and outside activities are presented.
3. Required Facilities, Equipment, and Materials—Materials—The required facilities, equipment and materials that should be available for presentation of the unit. The equipment and materials listed are divided into those which are educational and those which are content oriented (e.g., 16 mm projector vs. pitot tube).
4. Content Outline—Presents an organized outline of the topics to be covered during the presentation of the unit. The content outline is divided into the lesson outlines necessary for completion of the units.

In addition, the content outline contains instructions to the instructor and reference to slides and overlays that should be used in conjunction with the lecture. These instructions present the sequence of instructor activities, such as when to present a given slide, when a demonstration is required, or when an instructor's experience might be of value.

Since the course is designed to be taught by technically competent instructors, the material in the lesson content outline is of a topical nature with only that explanation present that should be emphasized to the student. It is expected that the instructor's skill and knowledge will allow for the depth

of presentation and emphasis required. The instructor is encouraged to present material relevant to experience, wherever possible, in order to provide the students with a referent to the subject.

5. **Demonstration Outlines**—Appropriate outlines for classroom and laboratory demonstrations and sample problems to be presented to the class. The demonstrations are designed to present an outline of the procedural steps that are important in performing the particular measurement, design, or calculation. Steps that are critical or that may lead to common errors are emphasized in the demonstration outlines.
6. **Practice Exercises**—A series of practice exercises that can be given to the student. These practice exercises can be used as either classroom or laboratory exercises or as homework assignments. Solutions to problems involving calculations are also provided.

Audio Visual Aids

A set of slides, which are referenced in the lesson outlines, have been prepared and are available for use in presenting the course.

Title Page	
Nonionizing and Ionizing Radiation	Module 6
<div>MODULE 6</div> <div>NONIONIZING AND IONIZING RADIATION</div> <div>INSTRUCTOR'S MANUAL</div>	

Unit and Lesson Topic Outline			
Nonionizing and Ionizing Radiation			Module 6
<p>The topics listed below are included within this module. The recommended time to be allotted for each topic is also given. Depending upon the particular class, this time may vary slightly; however, the total time for the entire module should not exceed the time given.</p>			
Unit	Lesson		Time/hrs.
1	Nonionizing Radiation		
	1 Principles of Nonionizing Radiation	2	Review of the basic properties, sources, biological effects, and TLV's of nonionizing radiation, including ultraviolet, infrared, radio frequencies, microwaves, and lasers. Also includes a discussion of the various applications of non-ionizing radiation, including related hazards.
	2 Control of Nonionizing Radiation	1	Review of methods of evaluation and control of ultraviolet and microwave radiation and lasers.
2	Ionizing Radiation		
	1 Principles of Ionizing Radiation	2	Review of the chemistry and physics of ionizing radiation, including both particulate and electromagnetic wave radiation. Also includes a discussion of the various applications of ionizing radiation and related hazards.
	2 Monitoring Instruments	1	Review of the instruments typically used to survey and monitor ionizing radiation sources, including ion chambers, proportional counters, G-M meters, dosimeters, and film badges.
	3 Control of Ionizing Radiation	2	Review of the basic concepts for monitoring and controlling ionizing radiation hazards. Included is a review of the uses of shielding, protective clothing, facilities design, and personnel monitoring.
			Total Module Time--8 Hours

Terminal Objectives	
Nonionizing and Ionizing Radiation	Module 6
<p>The objectives presented represent the competencies that the student should possess upon completion of this module. All objectives are directed toward the student's obtaining certain category levels of skill and knowledge.</p>	
Terminal Objectives	
<ol style="list-style-type: none"> 1. Upon request, the student will be able to write a paragraph that describes the properties of electromagnetic radiation. 2. Upon request, the student will be able to describe the difference between ionizing and nonionizing radiation. 3. Upon request, the student will be able to write a paragraph describing each type of radiation listed. The description will include the source, general application or use, biological effect, and protective measures normally taken to protect against each type of radiation. <ol style="list-style-type: none"> a. ultraviolet radiation b. infrared radiation c. microwave radiation d. alpha particles e. beta particles f. X-radiation g. gamma radiation h. neutrons 4. Given a situation describing the use of a nonionizing radiation source that is potentially dangerous, the student will be able to <ol style="list-style-type: none"> a. identify the radiation hazard b. recall at least two associated hazards related to the specified source c. describe the procedures necessary to further analyze the potential hazard d. using any references selected by the student, outline a procedure for minimizing or removing the hazard 	

Terminal Objectives	
Nonionizing and Ionizing Radiation	Module 6
<p>5. Given a situation describing the use of an ionizing radiation source and any references selected by the student, the student will be able to</p> <ol style="list-style-type: none"> calculate the potential radiation hazard. outline the procedure for controlling and mointoring the hazard. The outline must include a discussion of: <ol style="list-style-type: none"> (1) shielding requirements (2) changes in operating procedures (3) protective equipment used for personnel (4) changes in facilities design (5) monitoring procedures (including instrumentation) to be implemented (6) control of waste disposal (if applicable) <p>The description will include:</p> <ol style="list-style-type: none"> type and amount of radiation source description of the operating procedures and use of the radiation source present protective equipment and procedures being implemented location of personnel with respect to radiation source and mean exposure time of each of the personnel sample readings taken at the location of each of the personnel dimensions of the room any control devices presently being used that are not radiation oriented (e.g., ventilation systems) 	

Title Page	
Nonionizing Radiation	Module 6 Unit 1

UNIT 1

NONIONIZING RADIATION

Performance Objectives		
Lesson	Nonionizing Radiation	Module 6 Unit 1
1	1. Given a list of statements, the student will be able to recognize the one that best defines <ul style="list-style-type: none"> a. photon b. wavelength c. frequency d. relationship between wavelength and frequency 	
1	2. Given a list of regions on the electromagnetic spectrum, the student will be able to recognize the relative location of the region with respect to the other regions listed based upon frequency; e.g., ultraviolet has a higher frequency than infrared.	
1	3. Given a list of statements, the student will be able to select the one that best defines <ul style="list-style-type: none"> a. nonionizing radiation b. ionizing radiation c. relationship of ionizing and nonionizing radiation 	
1	4. Given a list of statements, the student will be able to recognize the statement that best describes <ul style="list-style-type: none"> a. region of electromagnetic spectrum b. potential sources for the radiation c. biological effects, including critical organ for each of the following regions: <ul style="list-style-type: none"> 1. ultraviolet 2. infrared 3. radio frequency (microwaves) 	
1	5. Given any references of the student's choice, the student will be able to determine the threshold limit value for a specified wavelength in the <ul style="list-style-type: none"> a. ultraviolet region b. infrared region c. radio frequency region 	
1	6. Given a list of statements, the student will be able to recognize the one that best describes the principle of operation of the <ul style="list-style-type: none"> a. klystron b. magnetron 	
1	7. Given a list of statements, the student will be able to recognize the one that best describes the principle of operation of a laser.	
1	8. Given no aids, the student will be able to recall and describe why lasers present a potential hazard.	

Performance Objectives		
Lesson	Nonionizing Radiation	Module 6
		Unit 1
1	9. Given a list of statements, the student will be able to recognize the one which best defines the difference between a CW and a pulsed laser.	
1	10. Given the <ul style="list-style-type: none"> a. output power b. pulse length c. focal size the student will be able to calculate the power density generated by a laser.	
1	11. Given no aids, the student will be able to recall at least one source and three related hazards for ultraviolet, infrared, and radio frequency regions.	
1	12. Given no aids, the student will be able to recall at least two uses and three related hazards for a laser.	
2	13. Given a list of statements, the student will be able to recognize the one(s) which best describe the principle of operation of ultraviolet detection devices; e.g., photon and thermal.	
2	14. Given a list of statements, the student will be able to recognize the one which best describes the need for ultraviolet survey instruments approximating the ultraviolet actinic curve.	
2	15. Given a series of incremental measurements from an ultraviolet source, a table of relative spectral effectiveness by wavelength, and the TLV table for effective irradiance, the student will be able to calculate the effective irradiance and if the TLV has been exceeded for a specified exposure time.	
2	16. Given a list of statements, the student will be able to recognize the one(s) which best describe factors affecting the accurate measurement of ultraviolet radiation.	
2	17. Given no aids, the student will be able to recall the effect of time and distance upon exposure level of electromagnetic radiation.	
2	18. Given a description of a work situation, including the exposure rate of ultraviolet radiation, the student will be able to calculate the maximum permissible time of exposure based upon the TLV.	
2	19. Given a situation describing the exposure level for specified wavelengths of ultraviolet radiation and a table of eyewear specifications, the student will be able to select the eyewear which attenuates the exposure below TLV for the given situation.	
2	20. Given the power output, beam divergence, beam diameter, and a formula to calculate beam intensity, the student will be able to calculate the beam intensity of a selected laser.	

Performance Objectives		
Lesson	Nonionizing Radiation	Module 6 Unit 1
2	21. Given a list of statements, the student will be able to recognize the one(s) which best describe(s) the principle of operation of laser survey instruments; e.g., photon, thermal.	
2	22. Given no aids, the student will be able to recall the criteria for classifying lasers in the five categories.	
2	23. Given a list of statements, the student will be able to recognize the one(s) which correctly define(s) operational requirements for a specified class of lasers; e.g., Class I--no requirements.	
2	24. Given a situation describing the exposure level for specified wavelengths of a laser and a table of eyewear specifications, the student will be able to select the eyewear which attenuates the exposure below TLV for the given situation.	
2	25. Given a list of statements, the student will be able to recognize the one which best describes the difference between the "near" and "far" field of radio frequency radiation.	
2	26. Given the antennae area and wavelength (radio frequency), the student will be able to calculate the radius of the near field.	
2	27. Given a list of statements, the student will be able to recognize the one(s) which best describe(s) the principle of operation of microwave detection devices; e.g., photon and electrical.	
2	28. Given no aids, the student will be able to recall at least five (5) potential hazards of radio frequency radiation to be evaluated.	

Unit Activities--Instructor	
Nonionizing Radiation	Module 6 Unit 1
<p>In order to present the unit material to the students, the instructor will be responsible for the following activities:</p> <p><u>Lesson 1--Principles of Nonionizing Radiation</u></p> <p><u>Classroom Presentation</u></p> <p>Conduct a discussion concerning the basic theory of nonionizing radiation. Specifically, ultraviolet, infrared, radio frequencies, microwaves, and lasers should be discussed. Also included is a discussion of the applications and related hazards.</p> <p><u>Time Allotted</u></p> <p>2 Hours</p> <p><u>Demonstrations</u></p> <p>No demonstrations are required.</p> <p><u>Supervised Practice</u></p> <p>No supervised practice is required.</p>	

Unit Activities--Instructor	
Nonionizing Radiation	Module 6 Unit 1
<p><u>Lesson 2--Control of Nonionizing Radiation</u></p> <p><u>Classroom Presentation</u></p> <p>Present a lecture on controlling nonionizing radiation. Specifically, ultraviolet radiation, microwave radiation, and lasers are discussed. Emphasis should be placed upon general concepts of control.</p> <p><u>Time Allotted</u></p> <p>1 Hour</p> <p><u>Demonstrations</u></p> <p>No demonstrations are required.</p> <p><u>Supervised Practice</u></p> <p>No supervised practice is required.</p>	

Unit Activities--Student

Nonionizing Radiation

Module 6

Unit 1

In order to complete the unit successfully, the student will be responsible for the following:

Lesson 1--Principles of Nonionizing Radiation

Classroom Activity

Attend a lecture concerning the basic theory of nonionizing radiation.

Assignment

The student should review the following materials prior to attending class.

READING	SHORT COURSE	EXTENDED 1-HOUR
Industrial Hygiene Engineering and Control		Section 6 Chapter 1
the Industrial Environment--its Evaluation and Control		Chapter 28 pp. 357-376
PROBLEMS		
Self-Test	Section 5	Section 5

Unit Activities--Student

Nonionizing Radiation

Module 6

Unit 1

In order to complete the unit successfully, the student will be responsible for the following:

Lesson 2--Control of Nonionizing Radiation

Classroom Activity

Attend a lecture on the control of nonionizing radiation.

Assignment

The student should review the following materials prior to attending class.

READING	SHORT COURSE	EXTENDED 1-HOUR
Industrial Hygiene Engineering and Control		Section 6 Chapter 2
PROBLEMS		

Facilities, Equipment, and Materials

Nonionizing Radiation

Module 6

Unit 1

Facilities

Lecture/discussion--normal classroom

Equipment

Educational

Chalkboard

Chalk

Eraser

35 mm slide projector with remote control

Screen

Health and Safety

Monitoring Devices

Ultraviolet radiation

Lasers

Microwave radiation

Visuals

Slide Series--Industrial Hygiene Engineering and Control

Module 6, Unit 1

References Used in Class

Industrial Hygiene Engineering and Control

the Industrial Environment--its Evaluation and Control

Lesson Outline	
Principles of Nonionizing Radiation	Module 6 Unit 1 Lesson 1
TOPIC	REMARKS
<p>I. Introduction</p> <p>A. Prior Module--Discussed Visible Radiation--Light</p> <ol style="list-style-type: none"> 1. Light has characteristics of waves and particles. 2. Light is energy released from de-excitation of electron. 3. Energy released in discrete units--quantum of energy--photon. 4. Each wave in visible spectrum has a characteristic: <ol style="list-style-type: none"> a. wavelength b. frequency c. photon energy 5. Characteristics can be correlated using the following: <ol style="list-style-type: none"> a. $C = f\lambda$, where C = speed of light $(3 \times 10^{10} \text{ cm/sec})$ f = frequency of oscillations/sec λ = wavelength (cm) b. $E = hf$, where E = photon energy (Joules) h = Planck's constant $(6.6 \times 10^{-34} \text{ Joule/sec})$ f = frequency of oscillations/sec 6. The importance of visible radiation--eye sensitive to this spectrum regions. <p>B. Electromagnetic Spectrum</p> <ol style="list-style-type: none"> 1. All radiations fundamentally alike in that they are produced by moving electrical charges. 2. Movement can be molecules, electrons, neutrons, etc. 	<p>Slide 6.1.1.--Radiation</p> <p>Briefly review topics discussed in last module which dealt with electromagnetic radiation.</p> <p>Slide 6.1.1.2.--Relationship of Frequency, Wavelength, and Photon Energy</p> <p>Slide 6.1.1.3.--Electromagnetic Spectrum</p>

Lesson Outline																																									
Principles of Nonionizing Radiation		Module 6 Unit 1 Lesson 1																																							
TOPIC	REMARKS																																								
<p>3. All radiation has same basic properties of visible radiation.</p> <p>II. Radiation--Overview</p> <p>A. Radiation--Emission of particles or energy in wave form.</p> <p>B. Vary in wavelength (λ) and frequency (f).</p> <p>C. Units of Measure</p> <p>1. Wavelength</p> <p>a. length from peak to peak</p> <p>b. units--see slide</p> <p>2. Frequency</p> <p>a. oscillations per second</p> <p>b. units--see slide</p> <p>3. Unit prefixes--used in conjunction with basic units.</p> <p>TABLE OF UNIT PREFIXES</p> <table> <tr> <th>Multiples and Submultiples</th><th>Prefix</th><th>Symbol</th></tr> <tr> <td>1,000,000,000,000 = 10^{12}</td><td>tetra-</td><td>T</td></tr> <tr> <td>1,000,000,000 = 10^9</td><td>giga-</td><td>G</td></tr> <tr> <td>1,000,000 = 10^6</td><td>mega-</td><td>M</td></tr> <tr> <td>1,000 = 10^3</td><td>kilo-</td><td>k</td></tr> <tr> <td>100 = 10^2</td><td>hecto-</td><td>h</td></tr> <tr> <td>10 = 10</td><td>deka-</td><td>D</td></tr> <tr> <td>0.1 = 10^{-1}</td><td>deci-</td><td>d</td></tr> <tr> <td>.01 = 10^{-2}</td><td>centi-</td><td>c</td></tr> <tr> <td>.001 = 10^{-3}</td><td>milli-</td><td>m</td></tr> <tr> <td>.000001 = 10^{-6}</td><td>micro-</td><td>μ</td></tr> <tr> <td>.000000001 = 10^{-9}</td><td>nano-</td><td>n</td></tr> <tr> <td>.000000000001 = 10^{-12}</td><td>pico-</td><td>p</td></tr> </table>	Multiples and Submultiples	Prefix	Symbol	1,000,000,000,000 = 10^{12}	tetra-	T	1,000,000,000 = 10^9	giga-	G	1,000,000 = 10^6	mega-	M	1,000 = 10^3	kilo-	k	100 = 10^2	hecto-	h	10 = 10	deka-	D	0.1 = 10^{-1}	deci-	d	.01 = 10^{-2}	centi-	c	.001 = 10^{-3}	milli-	m	.000001 = 10^{-6}	micro-	μ	.000000001 = 10^{-9}	nano-	n	.000000000001 = 10^{-12}	pico-	p	<p>Present an overview of the units that will be discussed in conjunction with nonionizing radiation.</p> <p>Slide 6.1.1.4.--Units of Measure--Wavelength</p> <p>Slide 6.1.1.5.--Units of Measure--Frequency</p> <p>Slide 6.1.1.6.--Table of Unit Prefixes</p> <p>It may be of value to review unit prefixes in the metric system to aid future discussions.</p>	
Multiples and Submultiples	Prefix	Symbol																																							
1,000,000,000,000 = 10^{12}	tetra-	T																																							
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<p>3. Types</p> <ul style="list-style-type: none"> a. alpha--helium nucleus b. beta--electrons c. neutrons <p>F. Radiation can be divided into two segments.</p> <ul style="list-style-type: none"> 1. Ionizing vs. nonionizing. 2. Based upon photon energy available. 3. Definition. <ul style="list-style-type: none"> a. ionizing--removal of electron from atom, forming positive and negative ion b. nonionizing--energy sufficient to excite atoms but not sufficient to remove electron 4. Known that 10 electron volts (eV) required to cause ionization of oxygen or hydrogen molecule; 10 eV can be set as lower limit for ionizing energy. 5. Using the equations. $E = hf$ $C = f\lambda$ <p>The minimum wavelength can be determined which causes ionization.</p> $E = hf \qquad C = f\lambda$ $\therefore E = \frac{Ch}{\lambda} \text{ or } \lambda = \frac{h \cdot C}{E}$ $\lambda = \frac{(6.6 \times 10^{-34} \text{ joule-sec}) \left(3.0 \times 10^{10} \frac{\text{cm}}{\text{sec}} \right)}{10 \text{ eV} \cdot 1.602 \times 10^{-19} \frac{\text{joules}}{\text{eV}}}$ $\lambda = 1.24 \times 10^{-5} \text{ cm}$ 	<p>Slide 6.1.1.10.--Ionizing vs. Nonionizing Radiation</p> <p>Ask students if they are familiar with "electron volt" as a unit of energy (force). If they are not, explain terminology.</p> <p>Slide 6.1.1.11.--Calculation of Minimum Ionization Wavelength</p>

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<p>6. Therefore, all radiation with λ greater than 1.24×10^{-5} cm will be considered non-ionizing, including</p> <ol style="list-style-type: none"> ultraviolet visible infrared radio frequency microwave 	<p>Slide 6.1.1.12.--Electromagnetic Spectrum Ionizing vs. Nonionizing Radiation</p> <p>Review the areas of the spectrum that are categorized ionizing and nonionizing with the students.</p> <p>Inform students that each segment of ionizing and nonionizing radiation will be presented in detail.</p>
III. Nonionizing Radiation--General	
<p>A. Definition--Radiation with sufficient energy to cause excitation of electrons, atoms, or molecules but insufficient energy to cause ionization.</p>	Slide 6.1.1.13.--Nonionizing Radiation--Definition
<p>B. Characteristics</p> <ol style="list-style-type: none"> All electromagnetic radiation. <ol style="list-style-type: none"> caused by moving charges electrical field with accompanying magnetic field Waves vary. <ol style="list-style-type: none"> wavelength (λ) frequency (f) intensity-strength--varies inversely with distance (d) by a factor of $1/d^2$--(inverse square law) Radiation can be considered in some instances discrete particles. <ol style="list-style-type: none"> quantum of energy--discrete energy and momentum if λ increases, energy decreases 	<p>Slide 6.1.1.14.--Nonionizing Radiation Characteristics</p> <p>This section is a review of characteristics presented for all radiation.</p>

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<p>4. No sharp dividing lines between regions--arbitrarily established.</p> <p>C. Sources</p> <p>1. Come from variety of sources.</p> <p>a. designed--microwave unit</p> <p>b. by-product--welders arc</p> <p>2. Examples.</p> <p>a. radio frequency--oscillating electrical current</p> <p>b. infrared--heated bodies--rotation of atoms</p> <p>c. visible--electron transition of energy levels</p> <p>3. Source of nonionizing radiation usually gives off more than one frequency.</p> <p>a. sun vs. welder's arc--broad band source</p> <p>b. radio antennae--must be filtered but essentially narrow band source</p> <p>D. Biological Effects</p> <p>1. Eye.</p> <p>a. very sensitive to radiation injury; e.g.,</p> <p>(1) conjunctivitis</p> <p>(2) keratitis</p> <p>b. not equally sensitive to all wavelengths--e.g., visible vs. ultraviolet</p> <p>c. can be indicator of radiation exposure because of sensitivity</p> <p>2. Thermal effect--body's absorption of nonionizing radiation causes heating of tissue.</p>	<p>Slide 6.1.1.15.--Nonionizing Radiation--Sources</p> <p>Ask students to give examples of each type of radiation listed.</p> <p>Slide 6.1.1.16.--Nonionizing Radiation--Biological Effects</p>

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3. Photochemical--causes chemical changes in body; e.g., development of pigment in skin from exposure to sun. 4. Carcinogenic--may catalyze tumors or cancer. IV. Nonionizing Radiation--Specific Regions A. To Be Discussed 1. Ultraviolet. 2. Visible. 3. Infrared. 4. Radio frequencies. 5. Microwaves. 6. Lasers. B. Ultraviolet Region 1. Highest energy region of the nonionizing radiation. 2. Normally divided into three regions. a. vacuum (1) $< 1.6 \times 10^{-5}$ cm (160 nm) (2) radiation can exist only in a vacuum (3) radiation completely absorbed by air b. far (1) $1.6 - 3.2 \times 10^{-5}$ cm (160-320 nm) (2) for λ --160-200 nm poorly transmitted through air --200-320 nm absorbed by ozone layer	Inform students that this section will deal with a. characteristics b. sources/application c. biological effects d. permissible exposure limit values for each region. Slide 6.1.1.17.--Ultraviolet Radiation Spectrum

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<p>c. near</p> <p>(1) $3.2-4.0 \times 10^{-5}$ cm (320-400 nm)</p> <p>(2) transmits through air particularly through glass</p> <p>d. most critical range is between 240-320 nm; highest biological effect in this range.</p> <p>3. Sources of ultraviolet radiation.</p> <p>a. sun</p> <p>(1) primarily radiation from middle and near region</p> <p>(2) typical solar radiation on a midsummer day, temperate latitude</p> <p>--total ultraviolet-daily cumulative dose ($\lambda < 400$ nm) = 2×10^{-3} J/cm²</p> <p>--only 1×10^{-5} J/cm² is erythemally effective (explained later)</p> <p>b. incandescent, fluorescent light sources</p> <p>c. welding operations</p> <p>d. plasma torches</p> <p>e. lasers</p> <p>4. Applications</p> <p>a. food sterilization--germicidal lamp</p>	<p>Slide 6.1.1.18.--Sources of Ultraviolet Radiation</p> <p>Ask students to give examples of uses of ultraviolet radiation and related hazards.</p> <p>Have students explain setup for process they are discussing. If necessary, draw diagram on chalkboard.</p>

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<ul style="list-style-type: none"> b. "black light"--blue-printing, laundry mark identification, dial illumination. c. fluorescent light sources d. by-product (source, not application) <ul style="list-style-type: none"> (1) sun--outdoor work (2) electric arc welding <p>5. Biological effects.</p> <ul style="list-style-type: none"> a. skin reddening (erythema effect) <ul style="list-style-type: none"> (1) absorption of ultra-violet radiation causes skin to redden (2) different λ has different effect <ul style="list-style-type: none"> -general erythema range, $\lambda = 240-320\text{nm}$ -maximum effect - 296.7 nm -minimal effect - 265-285 nm -secondary effect- 250 nm (3) signs/symptoms <ul style="list-style-type: none"> -dependent on dosage received -simple reddening, blisters -desquamation--peeling of skin (4) latent period--time required for onset of symptoms <ul style="list-style-type: none"> -dependent on dosage -may range from 2 to several hours -peak effect usually occurs 12-24 hrs after exposure 	<p>Slide 6.1.1.19.--Standard Erythema Curve</p>

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<ul style="list-style-type: none"> -symptoms will subside if UV source is removed (5) skin develops protective mechanism for subsequent exposures (suntan) increased pigmentation in upper layer of skin (6) dosage required to cause erythema <ul style="list-style-type: none"> -average Caucasian, 0.02-0.03 J/cm² -untanned skin requires less -Negroid skin--two to three times as much b. effect on the eye <ul style="list-style-type: none"> (1) conjunctivitis and keratitis <ul style="list-style-type: none"> -exposure above threshold limit value (TLV) causes inflammation of conjunctiva and cornea -cornea most vulnerable <ul style="list-style-type: none"> --anascular--cannot dissipate heat --abundance of nerve endings increases intensity of pain -maximum damage when $\lambda = 288 \text{ nm}$ -signs/symptoms <ul style="list-style-type: none"> --conjunctivitis; inflammation of conjunctiva --photophobia; abnormal intolerance of light --pain 	Slide 6.1.1.20.--Biological Effects--Ultra-violet Radiation

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<ul style="list-style-type: none"> --blepharitis-- inflammation of the eyelid --keratitis--inflam- mation of cornea --blepharospasms-- tight closing of lids, reflex pro- tective mechanism -latent period; time required for onset of symptoms --dependent on dosage --may take 30 min to 24 hrs to appear -e.g., welder's "flash burn" -symptoms regress after several days with no permanent damage -no tolerance is established because of repeated exposure <p>(2) fluorescence</p> <ul style="list-style-type: none"> -if $\lambda \approx 360$ nm, ex- cite the lens or vitreous humor of the eye -vitreous humor fluo- resces causing dif- fuse hazziness and decreased visual acuity -condition is strictly temporary and has no detri- mental effect -"internal haze" should disappear when exposure ceases 	<p>Explain term to students.</p>

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<p>c. carcinogenic effect</p> <ul style="list-style-type: none"> (1) ultraviolet radiation with $\lambda < 320$ nm related to cancer as catalyst (2) increased number of cases of skin cancer in outdoor workers who are simultaneously exposed to chemicals such as coal tar derivatives, benzopyrene, methyl cholanthrene and other anthracene compounds (3) however, no causes of industrially induced skin cancer reported to date; rationale--dosages required to cause cancer are in excess of dosage required to cause skin and eye burns; pain would be intolerable. <p>d. bactericidal effect</p> <ul style="list-style-type: none"> (1) nucleoproteins absorb peak at 160 nm; i.e., precipitation of proteins (2) causes irreparable damage to certain bacteria (3) low pressure mercury discharge lamps (254 nm) used as bactericides; can cause erythema and conjunctivitis <p>e. summary--review curve</p>	<p>Slide 6.1.1.21.--Ultraviolet Action Spectrum</p>

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<p>6. Other indirect effects.</p> <p>a. if $\lambda < 250$ nm; can cause dissociation of molecular oxygen to form ozone (O_3); ozone TLV = 0.1 ppm</p> <p>b. if $\lambda < 160$ nm (vacuum); can cause dissociation of molecular nitrogen which in turn reacts to form nitrogen oxides</p> <p>c. if $\lambda < 290$ nm; can cause the decomposition of chlorinated hydrocarbon (e.g., CCl_4, trichloroethylene) to form toxic gases; e.g., HCL, phosgene</p> <p>7. Exposure criteria.</p> <p>a. initial experimentation shows</p> <p>(1) threshold for injury to be 0.15×10^{-1} joules/cm² for $\lambda = 280$ nm</p> <p>(2) total ultraviolet radiation of 0.2 joules/cm² is necessary to produce damage</p> <p>b. according to ACGIH</p> <p>(1) for spectral region, 320-400 nm total irradiance</p> <p>(a) 1 mW/cm² for $>10^3$ second (16 min)</p> <p>(b) 1 joule/cm² for $<10^3$ second</p>	<p>Slide 6.1.1.22.--Indirect Effects of Ultraviolet Radiation</p> <p>Slide 6.1.1.23.--Exposure Criteria Ultraviolet Radiation ($\lambda = 320-400$ nm)</p>

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Principles of Nonionizing Radiation		Module 6 Unit 1 Lesson 1																																																
TOPIC	REMARKS																																																	
(2) for spectral region; 200-315 nm over 8-hr period is present in table. See slide.	Slide 6.1.1.24.--Ultraviolet Radiation TLV Values Relative Spectral Effectiveness by Wavelength <table> <tr> <th>Wavelength (nm)</th><th>TLV (mJ/cm²)</th><th>Relative Spectral Effectiveness--S_λ</th></tr> <tr><td>200</td><td>100</td><td>0.03</td></tr> <tr><td>210</td><td>40</td><td>0.075</td></tr> <tr><td>220</td><td>25</td><td>0.12</td></tr> <tr><td>230</td><td>16</td><td>0.19</td></tr> <tr><td>240</td><td>10</td><td>0.30</td></tr> <tr><td>250</td><td>7.0</td><td>0.43</td></tr> <tr><td>254</td><td>6.0</td><td>0.5</td></tr> <tr><td>260</td><td>4.6</td><td>0.65</td></tr> <tr><td>270</td><td>3.0</td><td>1.0</td></tr> <tr><td>280</td><td>3.4</td><td>0.88</td></tr> <tr><td>290</td><td>4.7</td><td>0.64</td></tr> <tr><td>300</td><td>10</td><td>0.30</td></tr> <tr><td>305</td><td>50</td><td>0.06</td></tr> <tr><td>310</td><td>200</td><td>0.015</td></tr> <tr><td>315</td><td>1000</td><td>0.003</td></tr> </table>		Wavelength (nm)	TLV (mJ/cm ²)	Relative Spectral Effectiveness--S _λ	200	100	0.03	210	40	0.075	220	25	0.12	230	16	0.19	240	10	0.30	250	7.0	0.43	254	6.0	0.5	260	4.6	0.65	270	3.0	1.0	280	3.4	0.88	290	4.7	0.64	300	10	0.30	305	50	0.06	310	200	0.015	315	1000	0.003
Wavelength (nm)	TLV (mJ/cm ²)	Relative Spectral Effectiveness--S _λ																																																
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(3) if broad band, must calculate effective irradiance to compare to standard TLV. $E_{\text{eff}} = \sum E_{\lambda} S_{\lambda} \Delta\lambda$, where E_{eff} = effective irradiance (W/cm ²) E_{λ} = spectral irradiance in W/cm ² /nm S_{λ} = relative spectral effectiveness $\Delta\lambda$ = band width in nanometers	Slide 6.1.1.25.--Effective Irradiance Calculation Discuss briefly equation and tables, but it will be repeated later. Inform students more time will be spent on TLV for all radiation during the discussion of recognition and control of nonionizing radiation.																																																	

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	Slide 6.1.1.26.--Effective Irradiance--TLV																														
	Permissible Ultraviolet Exposures																														
	<table> <tr> <th>Duration of Exposure Per Day</th><th>Effective Irradiance E_{eff} ($\mu W/cm^2$)</th></tr> <tr><td>8 hrs</td><td>0.1</td></tr> <tr><td>4 hrs</td><td>0.2</td></tr> <tr><td>2 hrs</td><td>0.4</td></tr> <tr><td>1 hr</td><td>0.8</td></tr> <tr><td>30 min</td><td>1.7</td></tr> <tr><td>15 min</td><td>3.3</td></tr> <tr><td>10 min</td><td>5</td></tr> <tr><td>5 min</td><td>10</td></tr> <tr><td>1 min</td><td>50</td></tr> <tr><td>30 sec</td><td>100</td></tr> <tr><td>10 sec</td><td>300</td></tr> <tr><td>1 sec</td><td>3,000</td></tr> <tr><td>0.5 sec</td><td>6,000</td></tr> <tr><td>0.1 sec</td><td>30,000</td></tr> </table>	Duration of Exposure Per Day	Effective Irradiance E_{eff} ($\mu W/cm^2$)	8 hrs	0.1	4 hrs	0.2	2 hrs	0.4	1 hr	0.8	30 min	1.7	15 min	3.3	10 min	5	5 min	10	1 min	50	30 sec	100	10 sec	300	1 sec	3,000	0.5 sec	6,000	0.1 sec	30,000
Duration of Exposure Per Day	Effective Irradiance E_{eff} ($\mu W/cm^2$)																														
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10 sec	300																														
1 sec	3,000																														
0.5 sec	6,000																														
0.1 sec	30,000																														
B. Visible Light--Discussed previously in module on Illumination.																															
C. Infrared Radiation (IR Radiation)	Slide 6.1.1.27.--Infrared Radiation--Location																														
1. Found at lower end of visible spectrum.																															
2. Range--750 nm - 10^{-1} cm.																															
3. Divided into two regions.																															
a. near region $< \lambda$ 750 nm, 5.0 μm																															
b. far region λ - 5.0-3000 μm																															
4. Sources of radiation.	Slide 6.1.1.28.--Infrared Radiation--Sources																														
a. hot furnaces																															
b. molten metals or glass																															
c. arc processes																															

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<p>5. Applications--generally heating</p> <ul style="list-style-type: none"> a. drying and baking of paints, varnishes, enamels b. heating of metal parts for forming, thermal aging, brazing c. dehydrating textiles, paper, leather, food-stuffs, sand molds d. spot and localized heating of desired object e. by-product (source, not application) <ul style="list-style-type: none"> (1) molten metal or glass (2) most arcing processes <p>6. Biological effect.</p> <ul style="list-style-type: none"> a. IR radiation perceptible as warmth to the skin b. for $\lambda > 1.5 \mu\text{m}$, energy absorbed by the skin because water content--absorption of energy causes an increase in temperature c. signs/symptoms <ul style="list-style-type: none"> (1) skin burn (2) vasodilation of capillary beds (3) erythema (4) blistering (5) pain (6) increased pigmentation d. no latent period e. extended exposure to intense IR radiation minimized because of pain provoked by exposure 	<p>Slide 6.1.1.29.--Infrared Radiation--Applications</p> <p>Slide 6.1.1.30.--Infrared Radiation--Biological Effect</p>

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<p>f. effect on the eye</p> <p>(1) IR radiation (near region) can cause damage to cornea, iris, lens, and retina</p> <p>(2) e.g.,</p> <p>--retinal burns</p> <p>--formation of cataracts (opacity of the lens); requires many years of daily exposure</p> <p>7.. Threshold limit values.</p> <p>a. concerned most exposure to eye</p> <p>b. damage dependent upon wavelength absorbed</p> <p>c. damage caused at levels of 4-8 J/cm²</p> <p>d. acceptable TLV: 0.4-0.8 J/cm²</p> <p>e. may be reduced by a second factor of ten (10) to reduce chronic effects</p> <p>D. Radio Frequencies</p> <p>1. Obey general laws of electromagnetic radiation.</p> <p>2. Range</p> <p>a. frequency: 1×10^{11} to 1×10^{12} Hz</p> <p>b. λ: 3×10^{-3} to 1×10^8 M</p> <p>3. Radio frequency induces</p> <p>a. electrical current in conductors</p> <p>b. displacement current in semi-conductors (transforms radiation energy to heat)</p>	<p>Slide 6.1.1.31.--Infrared Radiation--TLV</p> <p>Write on chalkboard.</p> <p>Slide 6.1.1.32.--Radio Frequencies</p> <p>Inform students that this discussion is radio frequencies in general and that microwaves, a subset of radio frequencies, will be discussed separately.</p>

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<p>4. Radio frequencies can be divided into two zones.</p> <p>a. caused because of wave interaction with source (antennae)</p> <p>b. near field (Fresnel zone)</p> <p>(1) field where interaction occurs</p> <p>(2) radius of field calculated by</p> $R = \frac{A}{2\lambda}$ <p>where</p> <p>R = radius of Fresnel zone (M)</p> <p>A = area of antennae (M²)</p> <p>λ = wavelength (M)</p> <p>(3) energy transmitted by both electric and magnetic vector in near field</p> <p>(4) energy difficult to measure in near field because of interaction--very complex process</p> <p>(5) if measured</p> <p>(a) volts/m for electric field</p> <p>(b) amps/m for magnetic field</p> <p>c. far field (Fraunhofer zone)</p> <p>(1) energy transmitted by electric vector only</p> <p>(2) field strength measured in volts/meter</p>	<p>Slide 6.1.1.33.--Fresnel Zone</p> <p>Moving electrical charges and magnetic fields generated were previously discussed in Module 4.</p>

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<p>(3) possible to relate power density and energy density by</p> $P = \frac{E^2}{120\pi}$ <p>where</p> <p>P = power density (W/m²)</p> <p>E = field strength (V/m)</p> <p>5. Sources</p> <ol style="list-style-type: none"> telecommunications high frequency heating scientific instruments--instrumentation chemistry <p>6. Application</p> <ol style="list-style-type: none"> heating <ol style="list-style-type: none"> metal--hardening metal surfaces, annealing wood working--bonding plywood, laminating food industry--sterilizing containers and killing bacteria molding plastics; curing and vulcanizing rubber radio communications <ol style="list-style-type: none"> broadcasting radar <p>7. Biological effects.</p> <ol style="list-style-type: none"> effect of radio frequency varies greatly in individuals; factor may be 100:1 	<p>Slide 6.1.1.34.--Radio Frequencies Sources/ Application</p> <p>Ask students to name sources of radio frequency and prepare list on chalkboard.</p> <p>Ask students to give practical examples of uses/sources of radio frequency radiation.</p> <p>Have students explain procedure for application and working environment. If necessary, draw a diagram on the chalkboard.</p> <p>Slide 6.1.1.35.--Radio Frequencies Biological Effects</p>

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<ul style="list-style-type: none"> b. generally affects the autonomic nervous system c. thermal effect <ul style="list-style-type: none"> (1) for an increase in body temperature, the body must have a diameter at least $1/10$ of the wavelength--$\lambda > 20$ m to have no thermal effect on the body (2) body acts as semi-conductor <ul style="list-style-type: none"> -electromagnetic radiation transformed to heat -absorption and transformation dependent upon water content -depth of penetration dependent upon fatty tissue (3) radio frequency may be reflected at interfaces of dielectrically nonhomogeneous layer, giving rise to "standing wave"--causes concentration of energy. (4) rate of energy absorption and heat accumulation dependent upon <ul style="list-style-type: none"> -field strength and power density -length of exposure; intermittent vs. continued -environmental temperature and humidity 	<p>Explain to students how each factor is important.</p>

Lesson Outline	
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<ul style="list-style-type: none"> -type of clothing -type of body layers -reflection of waves <p>(5) effect on specific organs; e.g.,</p> <p>(a) eye</p> <ul style="list-style-type: none"> --lens can be affected because of difficulty in heat dissipation --cell mitosis disrupted --cataracts may form <p>(b) testes--if temperature raised</p> <ul style="list-style-type: none"> --germ cells easily damaged --less androgen produced; decrease in sex hormone --pituitary hypofunction <p>(c) central nervous system</p> <ul style="list-style-type: none"> --thick bone, fatty content facilitate penetration and hinder heat dissipation --spherical shape may cause reflection and concentration of energy --brainstem and hypothalamus sensitive to radiation 	

Lesson Outline	
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<p>d. nonthermal effects</p> <p>(1) effect of electric/ magnetic field</p> <ul style="list-style-type: none"> -particles greater than 15 μm in diameter tend to polarize -no free histological structures $> 15 \mu\text{m}$ exist in body; therefore; polarization does not occur but potential for polarization exists <p>(2) demodulating effect</p> <ul style="list-style-type: none"> -affect organs displaying modulating electrical activity; e.g., heart, central nervous system -change in amplitude and peak frequencies in EEG and EKG <p>(3) molecular effect</p> <ul style="list-style-type: none"> -causes excitation of molecules -potential for molecular polarization -can exert catalytic action upon some chemical and enzymatic reactions <p>8. Hazards.</p> <p>a. thermal effect of electromagnetic radiation</p> <p>b. electrical hazards and potential X-radiation of high voltage equipment</p> <p>9. Safety limit standards.</p> <p>(a) limits based upon</p> <p>(1) thermal effects</p>	<p>Slide 6.1.1.36.--Radio Frequency TLV Levels</p>

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<ul style="list-style-type: none"> (2) nonthermal effects (3) individual sensitivity b. USSR health standards <ul style="list-style-type: none"> (1) 3-30 MHz <ul style="list-style-type: none"> (a) inductance heating <ul style="list-style-type: none"> --20 V/m (electrical field) --5 A/m (magnetic field) (b) dielectric heating, broadcasting <ul style="list-style-type: none"> --20 V/m (2) 30-300 MHz <ul style="list-style-type: none"> (a) 5 V/m (3) 300-300,000 MHz <ul style="list-style-type: none"> (a) 10 $\mu\text{W}/\text{cm}^2$--continuous exposure, average working day (b) 100 $\mu\text{W}/\text{cm}^2$--2 hrs per 24/hr period (c) 1 mW/cm^2--15 to 20 min per 24-hr period c. USA standard <ul style="list-style-type: none"> (1) continuous action across all frequencies (2) power density of 10 mW/cm^2 for 0.1 hr or longer (3) energy density of 1 mW/cm^2 for any 0.1 hour period 	<p>Slide 6.1.1.37.--Radio Frequency Exposure Criteria</p>

Lesson Outline	
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<p>E. Microwaves</p> <ol style="list-style-type: none"> 1. Radio frequencies above 1000 MHz are classified as microwaves. 2. Basic properties. <ol style="list-style-type: none"> a. acts as any electromagnetic radiation b. long-range transmission properties in air, including through rain and darkness c. follow a quasi-line-of-sight path with diffraction spreading d. may be readily generated with high power densities e. unique absorption properties in dielectric insulators leading to uniform heat disposition in many materials f. strongly reflected and contained by metallic surfaces 3. Types of microwaves. <ol style="list-style-type: none"> a. continuous wave (CW)--microwaves always being generated b. pulsed wave <ol style="list-style-type: none"> (1) on for a short period (one microsecond) then off for a long period (10^3 microseconds) (2) advantages--power obtained for short period greater than CW mode 	<p>Slide 6.1.1.38.--Microwaves-- Region/Basic Properties</p> <p>Slide 6.1.1.39.--Types of Microwaves</p>

Lesson Outline																			
Principles of Nonionizing Radiation	Module 6 Unit 1 Lesson 1																		
TOPIC	REMARKS																		
<p>4. Microwave frequencies used.</p> <p>a. established by FCC</p> <p>b. four frequencies selected for industrial, scientific and medical use (ISM)</p> <p>(1) 2450 ± 50 MHz is most commonly used in industry--microwave heating</p> <p>c. frequencies selected for communications</p>	<p>Slide 6.1.1.40.--Sample Microwave Frequency Assignments</p> <table> <tr> <th>Frequency</th><th>Wavelength</th></tr> <tr> <td>915 ± 25 MHz</td><td>32.8 cm</td></tr> <tr> <td>2450 ± 50 MHz</td><td>12.25 cm</td></tr> <tr> <td>5800 ± 75 MHz</td><td>5.17 cm</td></tr> <tr> <td>22125 ± 125 MHz</td><td>1.36 cm</td></tr> </table> <p>Give the students an example use of each specific frequency of microwave.</p> <p>Slide 6.1.1.41.--Sample Frequency Assignments</p> <table> <tr> <th>Designation</th><th>Wavelength</th></tr> <tr> <td>S band</td><td>10 cm</td></tr> <tr> <td>X band</td><td>3 cm</td></tr> <tr> <td>K band</td><td>1.2 cm</td></tr> </table>	Frequency	Wavelength	915 ± 25 MHz	32.8 cm	2450 ± 50 MHz	12.25 cm	5800 ± 75 MHz	5.17 cm	22125 ± 125 MHz	1.36 cm	Designation	Wavelength	S band	10 cm	X band	3 cm	K band	1.2 cm
Frequency	Wavelength																		
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Designation	Wavelength																		
S band	10 cm																		
X band	3 cm																		
K band	1.2 cm																		
<p>5. Sources of microwaves.</p> <p>a. practical sources; e.g.,</p> <p>(1) klystron--generates low power levels (1 watt)</p> <p>(2) magnetron--generates high power levels (1 Kwatt--on a CW basis)</p> <p>b. produced by deceleration of electrons in an electric field; as electrons slow down, energy released in the form of microwaves</p> <p>c. e.g., klystron</p> <p>(1) components</p> <p>(a) evacuated glass tube</p> <p>(b) electron emitting cathode</p>	<p>Slide 6.1.1.42.--Klystron--Schematic</p> <p>Briefly explain components of klystron and its operation.</p>																		

Lesson Outline	
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<ul style="list-style-type: none"> (c) accelerating (positive) grid (d) two metal ring-like microwave cavities <ul style="list-style-type: none"> --buncher (cavity and grids) --catcher (cavity and grids) (e) anode--catches (f) coaxial feed line <p>(2) operation</p> <ul style="list-style-type: none"> (a) high speed stream of electrons produced by cathode (b) electrons accelerated by accelerating grid (c) in buncher cavity, electrons modulated by microwave field into bunches (d) when bunched electrons pass catcher grid, electrons slow down and microwave radiation is produced (e) microwaves removed by coaxial cable (f) electrons captured at anode <p>(3) specific radiation released dependent on</p> <ul style="list-style-type: none"> (a) dimension of tube (b) dimension of cavity (c) velocity of electron 	

Lesson Outline	
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<ul style="list-style-type: none"> (4) reflex klystron most prominent; single cavity operation; principle the same d. e.g., magnetron <ul style="list-style-type: none"> (1) high power source (2) operates on same principle (3) variation vs. klystron <ul style="list-style-type: none"> (a) electric beam more intense because of circular orbit (b) multiple number of cavities; six or more (c) same cavities bunch electrons and slow down electrons (d) allows for more efficient cooling 	Slide 6.1.1.43.--Magnetron Schematic
<ul style="list-style-type: none"> 6. Biological effects. <ul style="list-style-type: none"> a. similar to biological effects caused by radio frequencies only more so b. thermal effect <ul style="list-style-type: none"> (1) more important vs. nonthermal (2) takes place throughout volume and does not originate from the surface (excessive penetration) (3) depth of penetration dependent on <ul style="list-style-type: none"> (a) frequency (b) type of tissue relative to water content 	Slide 6.1.1.44.--Microwaves-- Biological Effects

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<p>--fat and bone have low water content and absorption characteristics</p> <p>--skin and muscle have high water content and absorption characteristics</p> <p>(4) generally affects body as described in section on radio frequency radiation</p> <p>7. Nonthermal effects--same as for radio frequency; review for students.</p> <p>8. Exposure criteria</p> <table> <tr> <th><u>Power Density</u></th><th><u>Exposure Time Allowed</u></th></tr> <tr> <td>a. $< 10 \text{ mW/cm}^2$</td><td>8 hr (continuous exposure)</td></tr> <tr> <td>b. $>10 \text{ mW/cm}^2$ $< 25 \text{ mW/cm}^2$</td><td>10 min/60 min period during the day</td></tr> <tr> <td>c. $>25 \text{ mW/cm}^2$</td><td>No exposure</td></tr> </table> <p>F. Lasers</p> <ol style="list-style-type: none"> 1. Acronym--<u>L</u>ight <u>A</u>mplification by <u>S</u>timulated <u>E</u>mission of <u>R</u>adiation. 2. Can involve ultraviolet, infrared, visible, or microwave (maser) radiation. 	<u>Power Density</u>	<u>Exposure Time Allowed</u>	a. $< 10 \text{ mW/cm}^2$	8 hr (continuous exposure)	b. $>10 \text{ mW/cm}^2$ $< 25 \text{ mW/cm}^2$	10 min/60 min period during the day	c. $>25 \text{ mW/cm}^2$	No exposure	<p>Review effects for students, including:</p> <ol style="list-style-type: none"> a. general heating b. factors influencing rate of absorption of heat accumulation c. effect on specific oxygen <p>Slide 6.1.1.45.--Microwaves--Exposure Criteria</p> <p>Slide 6.1.1.46.--Laser</p>
<u>Power Density</u>	<u>Exposure Time Allowed</u>								
a. $< 10 \text{ mW/cm}^2$	8 hr (continuous exposure)								
b. $>10 \text{ mW/cm}^2$ $< 25 \text{ mW/cm}^2$	10 min/60 min period during the day								
c. $>25 \text{ mW/cm}^2$	No exposure								

Lesson Outline	
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<p>c. basic principle of operation; e.g., ruby crystal--steps involved</p> <ol style="list-style-type: none"> (1) flashtube flashes--optical pumping to excited level (2) chromium ions excited to metastable state (3) metastable state long lived but triggered when critical level of photons present (4) once critical level reached, presence of photons stimulates emission of other photons and chromium ions return to ground state again (5) simultaneous emission of photons forms coherent light (6) sequence requires approximately 10^{-3} seconds (7) coherent wave produced because of the critical level of photons required for <u>stimulated emission</u> <p>d. specific categories of lasers</p> <ol style="list-style-type: none"> (1) solid crystal with impurities. <ol style="list-style-type: none"> (a) e.g., ruby, neodymium doped glass (b) wavelength produced <ul style="list-style-type: none"> -ruby: 0.6943 micron wavelength -other: 1.06 micron wavelength 	<p>Slide 6.1.1.48.--Multi-Level Atomic Emitting System</p> <p>Explain to students the intermediate nonemitting energy levels involved in process. Draw examples of other multi-level excitation/de-excitation processes; e.g., four-level process.</p> <p>Ask students if they understand the concept of <u>stimulated emission</u>. If necessary, redefine the procedure.</p> <p>Slide 6.1.1.49.--Types of Lasers</p> <p>Have students refer to text.</p> <p>Inform students that specific type of laser is important only because of wavelength produced and potential power.</p>

Lesson Outline	
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<ul style="list-style-type: none"> (c) power obtainable to 100 watts (2) gaseous <ul style="list-style-type: none"> (a) e.g., molecular nitrogen (b) wavelength produced dependent upon optical cavity production (3) continuous gas laser <ul style="list-style-type: none"> (a) e.g., helium-neon laser (b) wavelength produced; e.g., 0.6238 microns (c) power range; 1 to 100 mwatts (4) semi-conductor diode laser <ul style="list-style-type: none"> (a) e.g., gallium arsenide (b) wavelength produced; e.g., 0.91 microns (c) power range; 20 watts e. types of operation <ul style="list-style-type: none"> (1) laser may be pulsed or continuous (2) continuous--laser continuously operating (3) pulsed--de-excitation of lasing materials over very short period of time (e.g., 10^{-6} seconds) causes tremendous increase in power density. 	<p>It is not necessary for the student to learn each category but only to be aware that different types exist.</p>

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<p>f. specific principles</p> <p>(1) coherence--all waves in phase</p> <p>(a) time coherence--in phase in a number of planes</p> <p>(b) space coherence--in phase across a given phase</p> <p>(2) beam divergence--very little variance in beam spread with distance from laser</p> <p>(a) two regions of beam spread</p> <p>-parallel region given by</p> $L = \frac{D^2}{2.44\lambda}$ <p>where</p> <p>L = parallel region</p> <p>D = beam diameter</p> <p>λ = wavelength</p> <p>-divergent region: beam diverges and intensity decreases such that</p> $\phi = \frac{1.22\lambda}{D}$ <p>where</p> <p>ϕ = beam divergence angle</p>	<p>Slide 6.1.1.50.--Wave Properties</p> <p>Slide 6.1.1.51.--Beam Divergence</p> <p>It is not necessary for the students to learn formulas. Information provided to clarify concept of beam divergence.</p>

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<p>(3) power density</p> <p>(a) can produce high power densities because</p> <ul style="list-style-type: none"> -pulsed system: energy emitted over short period of time -beam divergence minimized -coherent light can be focused on small image size <p>(b) power measured in terms of joules/sec or watts; if time of pulse decreased, watts increased</p> <p>(c) power density is defined as power per unit area; if area reduced; power density increases</p> <p>(d) laser produces peak power of 1 joule, but</p> <ul style="list-style-type: none"> -pulse is 10^{-6} seconds -focused on 1 mm^2 area <p>then becomes a power density of</p> $\frac{1 \text{ joule} \times \frac{1}{10^{-6} \text{ sec}}}{0.01 \text{ cm}^2} = 10^8 \text{ W/cm}^2$	<p>An example can be used that illustrates the importance of pulse width and focal size.</p> <p>Put example on chalkboard.</p>

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<p>(e) random reflecting surfaces</p> <p>-beam or section thereof may be reflected with little loss of intensity</p> <p>-important factor to consider during safety analysis</p> <p>5. Applications</p> <p>a. project reference lines for construction; e.g., laying pipelines, tunnels</p> <p>b. welding and micro-machining fine parts</p> <p>c. laser surgery</p> <p>(1) kill malignant tissue</p> <p>(2) remove warts and birthmarks</p> <p>d. transmit communication signals</p> <p>e. drilling through rock (tunnels)</p> <p>6. Biological effects.</p> <p>a. the eye and skin seem most vulnerable</p> <p>b. eye</p> <p>(1) dependent upon type of laser beam, namely</p> <p>-wavelength</p> <p>-output power</p> <p>-beam divergence</p> <p>-pulse repetition frequency</p> <p>(2) critical because of lens focusing beam on fovea--several magnitudes greater</p>	<p>Slide 6.1.1.52.--Laser Applications</p> <p>Ask students to give practical examples of use/source of laser operation.</p> <p>Have students explain procedure for application and working environment. If necessary, draw a diagram on the chalkboard.</p> <p>Slide 6.1.1.53.--Laser--Biological Effect</p>

Lesson Outline	
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<p>(3) general thermal</p> <ul style="list-style-type: none"> -heating of retina or cornea depending upon wavelength --visible light affects retina and retinal pigment; because of high intensity, protective reflex will prevent long duration of exposure; e.g., 10^{-6} W/cm² --cornea and skin affected with infrared and ultraviolet radiation; eye not sensitive to these λ; therefore, no protective reflex will be stimulated -retinal burns may occur if beam power is greater than 1 mW/cm² <p>c. general body</p> <ul style="list-style-type: none"> (1) severe damage to skin and underlying organs can be caused by high intensity beam (2) occasional exposure $< 1\text{mW/cm}^2$ is not expected to cause damage (3) <u>repeated</u> exposures between 10^{-3} and 10^{-6} W/cm² are undesirable <p>7. Hazards</p> <p>a. laser</p> <ul style="list-style-type: none"> (1) high energy beam--direct and reflected (2) high voltage equipment (X-radiation) 	

Lesson Outline	
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<ul style="list-style-type: none"> (3) ionization of air around beam may produce ozone (4) pressure in flash lamp may cause explosion b. associated equipment <ul style="list-style-type: none"> (1) cryogenic gases used as coolants (2) flammable solvents and materials associated with operation 8. Exposure criteria. <ul style="list-style-type: none"> a. exposure criteria dependent upon <ul style="list-style-type: none"> (1) continuous vs. pulsed, multiple pulsed (2) duration of exposure (3) direct or reflected beam (4) wavelength (5) skin vs. eye exposure b. because of the many factors, specific TLV values are available for various combinations 	<p>Slide 6.1.1.54.--Laser--Exposure Criteria</p> <p>Review generally the tables provided in the Instructor's Lesson Plans and textbook. Generally discuss trends apparent in TLV levels. Be sure to discuss exposure as it relates to:</p> <ul style="list-style-type: none"> a. continuous wave b. pulsed wave c. multiple pulsed train wave

Lesson Outline		
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TOPIC		REMARKS
V. Summary A. Discussed 1. Characteristics. 2. Sources/application. 3. Biological effects. 4. TLV For 1. Ultraviolet 2. Visible 3. Infrared 4. Radio frequencies 5. Microwave 6. Lasers		

Lesson Outline	
Control of Nonionizing Radiation	Module 6 Unit 1 Lesson 2
TOPIC	REMARKS
<p>I. Ultraviolet Radiation</p> <p>A. Range--Roughly 100-400 nm</p> <p>B. Specific Regions--Based Upon Effect on Man</p> <ol style="list-style-type: none"> 1. Keratitic <ol style="list-style-type: none"> a. inflammation of the cornea greatest b. 200-320 nm 2. Erythema--causing skin reddening. <ol style="list-style-type: none"> a. causing pronounced skin reddening and blistering b. 250-320 nm 3. Actinic--having a general adverse effect <ol style="list-style-type: none"> a. having general adverse effect on man b. 200-315 nm <p>C. Sources</p> <ol style="list-style-type: none"> 1. Sun--most UV below 300 nm; filtered by atmosphere. 2. Low intensity. <ol style="list-style-type: none"> a. low pressure mercury vapor b. sunlamps c. black-light lamp 3. High intensity. <ol style="list-style-type: none"> a. high pressure mercury vapor b. high pressure xenon arcs 	<p>Inform students that the discussion of control of nonionizing radiation will be limited to</p> <ol style="list-style-type: none"> a. ultraviolet radiation b. lasers c. microwaves <p>Sections A, B, and C are a review from the first lesson. Delete if appropriate.</p> <p>Slide 6.1.2.1.--Ultraviolet Radiation Spectrum This slide is in the first lesson.</p> <p>Slide 6.1.2.2.--Sources of Ultraviolet Radiation</p> <p>Review from Lesson 1.</p>

Lesson Outline	
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<ul style="list-style-type: none"> c. xenon-mercury arcs d. carbon arcs e. plasma torches f. welding arcs <p>D. Taking Measurements</p> <ol style="list-style-type: none"> 1. When measuring UV, measurement must reflect UV relative to effectiveness by wavelength; can be accomplished two ways: <ol style="list-style-type: none"> a. filtering system which mimics actinic curve; measures UV which has greatest effect on man b. if UV broad band source, must measure at specific wavelength and calculate effective irradiance (E_{eff}) <ol style="list-style-type: none"> (1) measure specific band widths (2) calculate exposure for each (3) adjust according to relative actinic spectral effectiveness (S_{λ}) (4) sum of all widths 2. Sample measurement. <ol style="list-style-type: none"> a. measurement instrument may <ol style="list-style-type: none"> (1) read power density directly (2) read amps and require conversion using calibration factor (calibration factor provided by manufacturer) 	<p>Slide 6.1.2.3.--Actinic Curve and Comparable Filtering</p> <p>Slide 6.1.2.4.--Effective Irradiance Formula</p> <p>Formula</p> $E_{eff} = \sum E_{\lambda} S_{\lambda} \Delta\lambda$ <p>where</p> <p>E_{eff} = effective irradiance</p> <p>E_{λ} = spectral irradiance (W/cm²/nm)</p> <p>S_{λ} = relative actinic spectral effectiveness (from table)</p> <p>$\Delta\lambda$ = band width (nm)</p>

Lesson Outline	
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<p>b. given</p> <p>(1) distance from source</p> <p>(2) time of exposure</p> <p>exposure can be calculated and compared to TLV</p> <p><u>Example</u></p> <p>Using a photometer, a reading of 0.5 μA is taken at 90 cm (the mean body/eye distance of the worker). If the worker is exposed to this radiation for approximately 15 minutes per 8-hour shift, is the TLV exceeded? What is the maximum exposure time per 8 hours? (Assume calibration factor = 90.6 $\mu\text{A}/\text{cm}^2/\mu\text{A}$ and filters corrected to 270 nm).</p> <p><u>Solution</u></p> $0.5 \mu\text{A} \times \frac{90.6 \mu\text{W}}{\text{cm}^2 \mu\text{A}} = \frac{45.3 \mu\text{W}}{\text{cm}^2}$ $\frac{45.3 \mu\text{J}}{\text{sec-cm}^2} \times \frac{900 \text{ sec}}{8 \text{ hr}} = \frac{40.77 \text{ mJ/cm}^2}{8 \text{ hr}}$ $\text{TLV} = \frac{3.0 \text{ mJ}}{\text{cm}^2} \text{ for 8-hour period}$ <p>Therefore: TLV exceeded</p> <p>Permissible exposure time in seconds for exposure to actinic ultraviolet radiation incident upon the unprotected skin or eye may be computed by dividing 0.003 J/cm² by E_{eff} in W/cm². The exposure time may also be determined using the table which provides exposure times corresponding to effective irradiances in $\mu\text{W}/\text{cm}^2$.</p> <p>What is maximum exposure time per 8-hrs?</p> $\frac{3.0 \text{ mJ}}{\text{cm}^2} \times \frac{\text{cm}^2 \text{ sec}}{45.3 \mu\text{J}} = 66 \text{ seconds}$	<p>Slide 6.1.2.5.--Example--Ultra-violet Exposure</p> <p>Slide 6.1.2.6.--Solution--Ultra-violet Exposure</p>

Lesson Outline	
Control of Nonionizing Radiation	Module 6 Unit 1 Lesson 2
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<p>E. Detection of Ultraviolet Radiation--Instruments</p> <ol style="list-style-type: none"> 1. Two major classes of detectors--based upon ultraviolet interaction. <ol style="list-style-type: none"> a. photometer b. thermal 2. Photoelectric devices. <ol style="list-style-type: none"> a. use phototube and photomultiplier. b. depend upon the ejection of an electron when UV interacts with metal c. photomultiplier used with low UV levels 3. Photovoltaic devices <ol style="list-style-type: none"> a. production of voltage difference in device caused by UV absorption b. e.g., <ol style="list-style-type: none"> (1) selenium photocells (2) silicon solar cells 4. Thermal devices <ol style="list-style-type: none"> a. production of voltage by increased temperature caused by UV absorption b. change in voltage proportional to UV radiation c. e.g., thermopile 5. Filters <ol style="list-style-type: none"> a. allow for discrimination of wavelengths b. discrimination necessary because of variation in effect of UV radiation wavelengths 	<p>Slide 6.1.2.7.--Instrumentation</p> <p>Review basic principles of each type of monitoring instrument. Briefly describe the advantages and disadvantages of each.</p> <p>It is appropriate to have sample monitoring equipment including probes and filters. Describe the typical use of monitoring equipment.</p> <p>Remind students of erythema curves versus wavelengths.</p>

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<p>c. effective irradiance can then be calculated.</p> <p>6. Monochrometer</p> <p>a. serves purpose of filter</p> <p>b. separates UV radiation into single wavelength</p> <p>c. allows analysis by wavelength</p> <p>F. Assume a monochromometer is used and the following readings obtained. Is the TLV exceeded if the average exposure is 30 minutes per 8-hour day?</p> <table><tr><td>λ (nm)</td><td>Reading ($\mu\text{W}/\text{cm}^2$)</td></tr><tr><td>200</td><td>0.08</td></tr><tr><td>220</td><td>0.09</td></tr><tr><td>240</td><td>0.18</td></tr><tr><td>260</td><td>0.18</td></tr><tr><td>280</td><td>0.27</td></tr><tr><td>300</td><td>0.36</td></tr></table> <p>$\Delta\lambda = 20\text{nm}$</p> <p><u>Solution</u></p> <p>$E_{(200)} = \frac{0.08\mu\text{W}}{\text{cm}^2} \cdot \frac{0.03}{\text{nm}} \cdot 20\text{nm} = 0.048\mu\text{W}/\text{cm}^2$</p> <p>$E_{(220)} = \frac{0.09\mu\text{W}}{\text{cm}^2} \cdot \frac{0.12}{\text{nm}} \cdot 20\text{nm} = 0.216$</p> <p>$E_{(240)} = \frac{0.18\mu\text{W}}{\text{cm}^2} \cdot \frac{0.30}{\text{nm}} \cdot 20\text{nm} = 1.08$</p> <p>$E_{(260)} = \frac{0.18\mu\text{W}}{\text{cm}^2} \cdot \frac{0.65}{\text{nm}} \cdot 20\text{nm} = 2.34$</p> <p>$E_{(280)} = \frac{0.27\mu\text{W}}{\text{cm}^2} \cdot \frac{0.88}{\text{nm}} \cdot 20\text{nm} = 4.752$</p> <p>$E_{(300)} = \frac{0.36\mu\text{W}}{\text{cm}^2} \cdot \frac{0.30}{\text{nm}} \cdot 20\text{nm} = \underline{2.16}$</p> <p style="text-align: right;">10.596 $\mu\text{W}/\text{cm}^2$</p> <p>Using table,</p> <p style="text-align: center;">$\text{TLV} = 1.7 \mu\text{W}/\text{cm}^2$</p> <p>Therefore, value is 6.2 times permissible value.</p>	λ (nm)	Reading ($\mu\text{W}/\text{cm}^2$)	200	0.08	220	0.09	240	0.18	260	0.18	280	0.27	300	0.36	<p>Slide 6.1.2.8.--Example--Effective Irradiance Calculation</p> <p>Refer to TLV tables, Module 6, Lesson 1, pages 6.25 and 6.26.</p> <p>Slide 6.1.2.9.--Solution--Effective Irradiance Calculation</p> <p>Relative Spectral Effectiveness by Wavelength</p> <table><tr><th>Wavelength (nm)</th><th>TLV (mJ/cm^2) *</th><th>Relative Spectral Effectiveness--Sλ</th></tr><tr><td>200</td><td>100</td><td>0.03</td></tr><tr><td>220</td><td>25</td><td>0.12</td></tr><tr><td>240</td><td>10</td><td>0.30</td></tr><tr><td>260</td><td>4.6</td><td>0.65</td></tr><tr><td>280</td><td>3.4</td><td>0.88</td></tr><tr><td>300</td><td>10</td><td>0.30</td></tr></table> <p>* $1 (\text{mJ}/\text{cm}^2) = 10^{-3} \text{ J}/\text{cm}^2$</p>	Wavelength (nm)	TLV (mJ/cm^2) *	Relative Spectral Effectiveness--S λ	200	100	0.03	220	25	0.12	240	10	0.30	260	4.6	0.65	280	3.4	0.88	300	10	0.30
λ (nm)	Reading ($\mu\text{W}/\text{cm}^2$)																																			
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<p>G. Factors Influencing Measurements-- To avoid errors of major magnitude, the following must be considered:</p> <ol style="list-style-type: none"> 1. Monitoring instrument must match spectral output of UV source. 2. Solarization or aging of lenses may require periodic calibration. 3. Water vapor in atmosphere. <ol style="list-style-type: none"> a. reduces readings by absorbing UV b. affects electronic circuitry 4. Meters directional. 5. Reflection of UV from nearby source or high intensity visible light can affect reading. 6. Inverse square law must be considered--distance critical to measurement. <p>H. Personnel Protection</p> <ol style="list-style-type: none"> 1. Primary concern is exposure to skin and eyes. 2. Three protective tools which can be used: <ol style="list-style-type: none"> a. time b. distance c. shielding 3. Time. <ol style="list-style-type: none"> a. by decreasing time of exposure, total exposure decreased. 	<p>Slide 6.1.2.10.--Factors Influencing Measurements</p> <p>Inverse square law should be briefly described to the students.</p> <p>Slide 6.1.2.11.--Protective Tools</p> <p>Point out that first example illustrated that TLV would not be exceeded for 8-hour period of personnel exposed for only 66 seconds rather than 15 minutes per 8-hour segment.</p>

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<ul style="list-style-type: none"> b. when analyzing potential hazard, important to know time of exposure to calculate potential exposure c. analysis of job may indicate procedure changes that may reduce exposure time <p>4. Distance.</p> <ul style="list-style-type: none"> a. intensity is decreased by the square of the change in distance (inverse square law) b. e.g., if reading is $\frac{15\mu W}{cm^2}$ at 1 ft, it will be $\frac{15}{(2)^2} = \frac{3.75\mu W}{cm^2}$ at 2 feet c. distance may not be a useful tool because of type of work involved; e.g., welding d. two important points <ul style="list-style-type: none"> (1) all measurements should be taken at distance that approximates worker distance; if hands are normally closer, measurements should be taken at those distances (2) effort should be made to maximize distance to minimize exposure; e.g., use of tongs to handle materials; automation 	<p>Inform the students that the "inverse square law" does not apply to lasers.</p> <p>Put example on chalkboard.</p>

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<p>5. Shielding.</p> <ul style="list-style-type: none"> a. necessary to shield the skin and eyes specifically b. can be done using three types of shielding <ul style="list-style-type: none"> (1) enclosures (2) protective clothing (3) eye protection c. enclosures <ul style="list-style-type: none"> (1) minimize exposure to <ul style="list-style-type: none"> -person working directly with UV source -personnel in vicinity (2) selection of enclosure material dependent upon <ul style="list-style-type: none"> -wavelength -properties of wavelength involved --reflectance --absorption characteristics -e.g., clear glass opaque to UV and transparent to visible light -e.g., red opaque filter--opaque to visible light; transparent to UV source (3) any enclosure area should be adequately marked and labeled as a radiation area 		

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<p>6. Miscellaneous hazard control.</p> <p>a. associated nonradiation hazards must also be considered</p> <p>(1) high voltage</p> <p>(2) ozone production</p> <p>(3) chemical reactions</p> <p>b. high voltage</p> <p>(1) instrument producing UV may require high voltages for operation; possible electrocution</p> <p>(2) high voltage may precipitate the extraneous production of X-radiation.</p> <p>c. ozone production</p> <p>(1) UV reacts with oxygen (O_2) in atmosphere to produce ozone (O_3); may be several feet away</p> <p>(2) adequate ventilation necessary.</p> <p>d. chemical reactions</p> <p>(1) UV reduces chlorinated hydrocarbons (trichloroethylene) to toxic substance</p> <p>(2) UV causes formation of nitrogen oxides</p> <p>(3) forms toxic fumes if procedure involves base metals including elements such as zinc, beryllium, lead, cadmium</p>	<p>Inform students that control of IR radiation is similar to UV radiation.</p> <p>Slide 6.1.2.15.--Nonradiation Hazards</p> <p>X-radiation discussed in Unit 2.</p> <p>Briefly describe toxic properties of O_3. TLV = 0.1 ppm:O_3.</p> <p>Slide 6.1.2.16.--Ventilation System/Welders</p>

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<p>(4) because of potential chemical reactions</p> <p>-location of UV source must be evaluated; e.g, near degreasing operation using chlorinated solvents</p> <p>-adequate ventilation must be provided</p> <p>I. General Survey Techniques</p> <p>1. When surveying area, a diagram of area should be prepared indicating</p> <p>a. UV source</p> <p>b. personnel location</p> <p>c. protective devices in use; e.g.,</p> <p>(1) signs</p> <p>(2) screens</p> <p>d. potential hazards; e.g., lack of ventilation</p> <p>2. Sample form can be used as a basis for the survey.</p> <p>3. Form review.</p> <p>a. USING ORGANIZATION-- company or division</p> <p>b. ADDRESS--</p> <p>c. TYPE OF EQUIPMENT--UV source, e.g., welder, germicidal lamp, xenon lamp</p> <p>d. INTENDED USE--purpose of source; e.g., research construction material testing</p> <p>e. MANUFACTURER--model, serial number; identifies special source</p>	<p>Slide 6.1.2.17.--Sample Survey Form</p> <p>Have students examine sample form in textbook.</p> <p>Briefly review key information on form. It is not necessary to cover each component in great detail.</p>

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<ul style="list-style-type: none"> f. OTHER--general information g. WELDER ONLY--refers to operating parameter of welder <ul style="list-style-type: none"> (1) GAS-- (2) VOLTAGE/CURRENT--if electric welder is used (3) FILLER--welding rod (4) MATERIAL--material being welded; including coatings (5) DUTY CYCLE--operation time in 8-hour shift of any UV source h. MONITORING INSTRUMENT--device used to monitor UV i. PROBE--detector used j. FILTER--type of filter k. ATTACHMENTS--attenuators, screen, beam splitter used l. WAVELENGTH RANGE--sensitivity range of monitoring system m. DISTANCE TO SOURCE--distance from measure point to source n. D/R <ul style="list-style-type: none"> (1) D--direct reading (2) R-reflected reading o. KEY--keyed location on diagram p. INSTRUMENT READING--$\mu\text{W}/\text{cm}^2$ q. EXPOSURE TIME--average exposure per 8-hour day to level of exposure measured r. EXPOSURE/DAY-- s. ENVIRONMENT--drawing of area, including <ul style="list-style-type: none"> (1) UV source (2) point of measurement (3) personnel location (time of exposure/day) (4) non-UV hazards (5) protection devices 	

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<p>t. PERSONNEL--the type of personnel (e.g., student, machinist, etc.), location, and exposure time/day should be recorded.</p> <p>u. PERSONNEL PROTECTION--</p> <p>(1) existing protection devices</p> <p>(2) recommended protection devices added; e.g., paint walls to reduce reflection</p> <p>v. SURVEY BY/DATE--signature of surveyor.</p>	<p>NOTE: The form is not intended to be standard but a guide to needed information.</p> <p>Give examples of UV hazard and procedures for control.</p> <p>Review and assign Practice Exercise pertaining to UV radiation.</p>

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ULTRAVIOLET RADIATION SURVEY											
GENERAL INFORMATION	USING ORGANIZATION						ADDRESS				
	TYPE OF EQUIPMENT						INTENDED USAGE				
	MANUFACTURE		MODEL		SERIAL NUMBER			OTHER			
HAZARD DETERMINATION	WELDER ONLY	GAS	CURRENT	VOLTAGE	FILLER	MATERIAL	DUTY CYCLE				
	MONITORING INSTRUMENT				PROBE		FILTER				
	ATTACHMENT				WAVELENGTH OR WAVELENGTH RANGE						
	DISTANCE TO SOURCE (METERS)		D/R	KEY	INSTRUMENT READING ($\mu\text{W}/\text{cm}^2$)	EXPOSURE TIME 8/HR	EXPOSURE/DAY ($3 \times 10^{-3} \text{ J}/\text{cm}^2$) IRRADIANCE				
ENVIRONMENT											
PERSONNEL	BACKGROUND SAFETY TRAINING UNAWARE ONLOOKER OTHER										
PERSONAL PROTECTION	IN USE	SIGNS EYE PROTECTION RESTRICTED AREA GLOVES				SKIN CREAM CLOTHING CURTAINS ENCLOSURES			PARTITIONS OTHER		
	RECOM- MENDED										
SURVEYED BY						DATE					

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<p>II. Lasers</p> <p>A. Hazard</p> <ol style="list-style-type: none"> Reason for hazard--concentration of energy on a point target. Predominately affects <ol style="list-style-type: none"> eye--parallel rays may be focused to a point image skin TLV established for eye and skin. <p>B. Measurement of Laser Beam</p> <ol style="list-style-type: none"> Number of periodic measurements not necessary for protection program because <ol style="list-style-type: none"> accuracy of manufacturers' specifications high cost of detectors complexity of radiometric measurement techniques Possible to beam intensity (I) at a selected range. <ol style="list-style-type: none"> must know <ol style="list-style-type: none"> power output (E) in watts range of interest (r) in centimeters beam divergency (ϕ) in radians beam diameter (a) in mm formula $I = \frac{Ee^{-ur}}{[(\pi/4)(a + r\phi)]^2}$ 	<p>Slide 6.1.2.18.--Lasers</p> <p>Slide 6.1.2.19.--Observing Laser Light</p> <p>Slide 6.1.2.20.--Beam Intensity</p> <p>Note: (e^{-ur}) is atmospheric attenuation and can be ignored if range less than 10 kilometers.</p> <p>r = range in cm u = attenuation/cm</p>

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<p>c. using same equation, can calculate</p> <p>(1) maximum viewing time at given distance</p> $t = (I_t E) \left[(0.7854(a + r\phi)) \right]^2$ <p>where</p> <p>t = time (sec)</p> <p>I_t = TLV (Joule/cm²) - wave-length specific</p> <p>E = power output (Joule/sec - W)</p> <p>a = beam diameter (cm)</p> <p>r = specified distance (cm)</p> <p>ϕ = beam divergence (radians)</p> <p>(2) minimum viewing distance given a specified viewing time</p> $r = \frac{\left[\frac{\left(\frac{E \cdot t}{I_t} \right)^{\frac{1}{2}}}{0.7854} \right] - a}{\phi}$ <p>3. Must know</p> <p>a. wavelength and TLV</p> <p>b. approximate direct viewing time for 8-hour period</p> <p>c. minimum (average) viewing distance during direct viewing</p>	<p>Slide 6.1.2.21.--Calculation of Maximum Viewing Time Given Distance</p> <p>If necessary, derive formula for students.</p> <p>Slide 6.1.2.22.--Calculation of Minimum Viewing Distance Given a Specified Viewing Time</p>

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<p>B.</p> $r = \frac{\left[\frac{\left(\frac{E \cdot t}{I_t} \right)^{\frac{1}{2}}}{0.7854} \right] - a}{\phi}$ <p> $E = 2.25 \text{ mW}$ $I_t = 250 \text{ mj/cm}^2$ $t = 3 \times 60 = 180 \text{ sec}$ $a = 1.5 \text{ cm}$ $\phi = 10^{-4} \text{ radians}$ </p> $r = \frac{\left[\frac{\left(\frac{2.25/180}{250} \right)^{\frac{1}{2}}}{0.7854} \right] - 1.5}{10^{-4}}$ <p>$r = 1200 \text{ cm}$</p> <p>4. Photon devices.</p> <ol style="list-style-type: none"> measure rate at which light quanta are absorbed e.g., <ol style="list-style-type: none"> photoelectric photoconductive photovoltaic <p>5. Thermal devices.</p> <ol style="list-style-type: none"> measure effect of heat and temperature change when absorbing light energy e.g., <ol style="list-style-type: none"> calorimeter bolometer thermocouple 	<p>Slide 6.1.2.25.--Solution--Part B</p> <p>This example illustrates the importance of properly controlling laser operation. If the direct viewing is increased by 25 seconds (180-155), the safe viewing distance varies from 50 cm to 1206 cm (a 24-fold increase).</p> <p>It may be appropriate to have an instrument available and briefly describe</p> <ol style="list-style-type: none"> components basic use steps for use

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<ul style="list-style-type: none"> c. e.g., Class III <ul style="list-style-type: none"> (1) well-controlled area (2) no specular surfaces (3) terminate beam with diffuse material and minimum reflection (4) eye protection for direct beam viewing d. e.g., Class II <ul style="list-style-type: none"> (1) posting of signs in area (2) control of beam direction e. Class I--no requirement 4. Further, the following guidelines are presented for consideration. <ul style="list-style-type: none"> a. laser attended during all times of operation b. personnel educated in operation of laser potential hazards c. non-instructed personnel <u>not</u> permitted in laser area d. laser equipment and area properly posted e. direct viewing should not be done using binoculars or telescope f. laser should not be aimed at occupied areas without appropriate shielding g. methods of confining laser plumes and laser-induced vaporization should be used h. nonreflecting surfaces should surround laser area i. beams passing through glass should pass through perpendicularly j. beam direction should be controlled and minimized k. combustible solvents and materials should be stored away from laser 	<p>Slide 6.1.2.29.--Class III Requirements</p> <p>Slide 6.1.2.30.--Class II Requirements</p>

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<p>1. potential non-laser hazards should be considered.</p> <p>(See other side of outline)</p>	<p>Put on chalkboard.</p> <p><u>Potential Non-Laser Hazards</u></p> <ol style="list-style-type: none"> Voltage sources and leads. X-radiation from high-voltage sources. Ozone generation from high-voltage sources and ultra-violet radiation. Underground electrical equipment, including laser heads and work stations. Toxic materials. Combustible materials. Chemically active materials. Cryogenic fluids. Inert purging gases. Flash-lamp explosion. Radiation other than laser beam may also be hazardous. Violent interactions can occur during the interaction of laser radiation and materials. Explosions, fires, chemical reactions, brilliant plumes, and toxic emission may occur. Mechanical items may break. High-speed mechanical scanners, Q-switches, choppers, and so forth, can fatigue and break. Interlocks may fail. Accidental discharging of laser can occur. Ultraviolet and infrared beams cannot be seen. Fallible human beings operate lasers.
<p>m. protective eyewear should be provided in any instance where potential exposure is above $1\mu\text{W}/\text{cm}^2$</p>	<p>Will be discussed later more specifically.</p>

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<p>n. periodic (annual) medical examinations, including eye examination, should be performed on all personnel working near laser</p> <p>5. Eye protection.</p> <p>a. provided when exposure may exceed $1\mu\text{W}/\text{cm}^2$</p> <p>b. eyewear design</p> <p>(1) prevent observation of reflected beam; side panels necessary</p> <p>(2) curved lenses--diffuse beam</p> <p>c. eyewear parameters</p> <p>(1) wavelength--must absorb all wavelengths emitted</p> <p>(2) optical density--must reduce intensity to acceptable level (optical density = $\log_{10} \frac{1}{\text{transmittance}}$)</p> <p>(3) laser beam irradiance; based upon maximum output potential of laser</p> <p>(4) visible transmittance--filter out laser; transmit maximum visible light</p> <p>(5) filter damage threshold--filters damaged by high-energy lasers</p> <p>d. method of construction</p> <p>(1) spectral absorption by filter</p> <p>(2) selective reflection from dielectric coating</p>	<p>Will be discussed later more specifically.</p> <p>Slide 6.1.2.31.--Protective Eyewear--Goggles</p> <p>Slide 6.1.2.32.--Protective Eyewear--Curved Lenses</p> <p>Slide 6.1.2.33.--Eyewear Construction--Dielectric Plate</p>

Lesson Outline

Control of Nonionizing Radiation

Module 6

Unit 1

Lesson 2

Laser Eye Protection Goggles Based on Manufacturers' Information† OPTICAL DENSITY = $\log_{10} \frac{1}{\text{Transmittance}}$

Manufacturer or Supplier	Catalogue Number	Argon • 4880 Å	HeNe • 6328 Å	Ruby • 6943 Å	GaAs • 8400 Å	Nd 10600 Å	CO ₂ 10.6 μ	UV • < 4000 Å	> 3000 Å	Coated Filter	Approx. Cost \$	No. of glass filters & thickness of each	Visible Light trans-mission	Useful Range • Å
American Optical Co.	SCS-437,*	0.15	0.20	0.36	1	5	High	No	No	No	55	1, 3.5 mm	90 %	10600
	SCS-440													10600
	580, 586*	0.2	2	3.5	4	2.7	—	> 0.2	No	No	35, 25*	1, 3.5 mm	27.5%	—
	581, 587*	0.6	4.1	6.1	5.5	3	—	> 1.6	No	No	35, 25*	1, 3.5 mm	9.6%	6328
	584	0	1	5	13	11	High	> 0.6	No	No	55	2, 2 mm	46 %	10600
	585	0.3	2	8	21	17	High	> 0.6	No	No	55	2, 2 mm	35 %	6943-10600
	590*	13	0	0	0	—	—	> 14	No	25*	1, 3 mm	23.7%	4550-5150	
	599	11	0	0	0	—	—	> 14	No	No	35	1, 2.5 mm	24.7%	4550-5150
	680	0	0	0	0	0	50	No	No	35	1, 2.7 mm	92 %	10600	
698	13	1	4	11	8.5	High	> 14	No	No	55	2, 2&3mm	5 %	10600 and 5300	
Bausch & Lomb	5W3754	15	0.2	0	0	0	Vi 35	20	Yes	39	1, 7.9 mm	4.3%	3300-5300	
	5W3755	4	0	0	0	0.1	Vi 35	10	Yes	39	1, 7.9 mm	57 %	4000-4600	
	5W3756	0.8	12	15	5.6	4.8	Vi 35	3	Yes	39	1, 6.4 mm	6.2%	6000-8000	
	5W3757	0.9	4.5	7.7	12	5.7	Vi 35	2	Yes	39	1, 7.1 mm	4.7%	7000-10000	
	5W3758	1.9	1.8	2.2	4.8	7.5	Vi 35	2	Yes	39	1, 7.6 mm	3 %	10000-11500	
Control Data Corp.	TRG-112-1	—	5	12	30	30	—	No	No	50	1, 6 mm	22 %	6943	
	TRG-112-2	10	0	0	0	0	—	No	No	50	1, 6 mm	31 %	4880	
	TRG-112-3	5	2	6	15	15	—	No	No	50	2, 3 mm	5 %	6943-4880	
	TRG-112-4	—	—	—	—	—	High	No	No	50	1, 5 mm	92 %	106000	
Fish-Schurman Corp.	FS650AL/18	0.34	3.8	10	>10	>10	—	No	No	No	30	1, 6 mm	30 %	6943, 8400, 106000
Glendale Optical Co.	NDGA**	1	0.5	2	16	16	High	>20	No	No	25	Plastic	60 %	8400, 10600
	R**	0.4	2.2	6.3	0.4	0.0	High	5	No	No	25	Plastic	19 %	6943
	NH**	0.4	5	2.5	0.6	0.5	High	>10	No	No	25	Plastic	19 %	6328
	A**	15	0	0	0	0	High	>12	No	No	25	Plastic	59 %	4880, 5143
	NN**	0	0	0	0	0	High	>12	No	No	25	Plastic	70 %	3320, 3370
Spectrolab	—	8	5	9	13	12	0	8	Yes	115	2, 3.2 mm	<5 %	Broadband	

*Spectacle Type. †See reference 24.

**Available in goggles or spectacle type.

CAUTION

1. Goggles are not to be used for viewing of laser beam. The eye protective device must be designed for the specific laser in use.
2. Few reliable data are available on the energy densities required to cause physical failure of the eye protective devices.
3. The establishment of engineering controls and appropriate operating procedures should take precedence over the use of eye protective devices.
4. The hazard associated with each laser depends upon many factors, such as output power, beam divergence, wavelength, pupil diameter, specular or diffuse reflection from surfaces,

Reprinted from the Industrial Environment--its Evaluation and Control

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Control of Nonionizing Radiation	Module 6 Unit 1 Lesson 2
TOPIC	REMARKS
<ul style="list-style-type: none"> e. using paramaters discussed, select appropriate eyewear. <p>6. Medical surveillance.</p> <ul style="list-style-type: none"> a. medical examination should be given to all personnel working near laser. b. examination should include <ul style="list-style-type: none"> (1) ophthalmologic examination (2) dermatologic examination c. persons with following conditions should not be permitted to work near lasers <ul style="list-style-type: none"> (1) eye disease (2) skin problems (3) chronic pulmonary or cardiovascular disease (4) chronic emotional and mental illness (5) hypothyroidism (6) diabetes (7) pregnancy <p>7. Summary.</p> <ul style="list-style-type: none"> a. general hazard b. measurement of lasers c. control of hazards d. eye protection e. medical surveillance 	<p>Slide 6.1.2.34.--Laser Eye Protection Chart</p> <p>Have students examine chart in textbook. Briefly review data on chart.</p> <p>Slide 6.1.2.35.--Medical Surveillance</p>

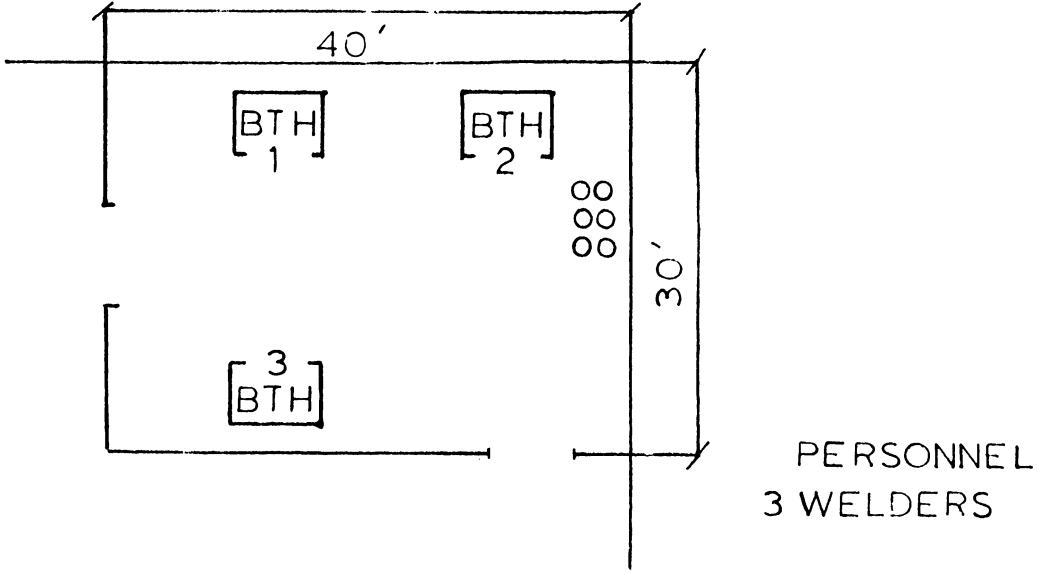
Lesson Outline	
Control of Nonionizing Radiation	Module 6 Unit 1 Lesson 2
TOPIC	REMARKS
<ul style="list-style-type: none"> b. effective area of antennae (A) (cm²) c. average power output (A) (mW) d. power density (W) (mW/cm²) e. formula $r \text{ (safe distance) } = \left(\frac{A \cdot P}{\lambda^2 \cdot W} \right)^{0.5}$ <p>3. Survey instruments.</p> <ul style="list-style-type: none"> a. most survey instrumentation designed to measure in far field b. usually calibrated in mW/cm² c. measurements in near field (calculated using previous equation) more complicated d. generally, far field measurements adequate <p>4. Measuring instruments.</p> <ul style="list-style-type: none"> a. microwave survey instruments consist of <ul style="list-style-type: none"> (1) probe (2) meter and amplifier (3) power source b. general instrument requirements <ul style="list-style-type: none"> (1) portable (2) rugged (3) easily readable (4) probe--directionally independent c. detectors--two categories <ul style="list-style-type: none"> (1) thermal (2) electrical 	<p>Consumer Product Safety does this measurement on products.</p> <p>Slide 6.1.2.38.--Components of a Microwave Survey Instrument</p> <p>Slide 6.1.2.39.--Microwave Detectors</p>

Lesson Outline	
Control of Nonionizing Radiation	Module 6 Unit 1 Lesson 2
TOPIC	REMARKS
<p>d. thermal detector</p> <ul style="list-style-type: none"> (1) absorption of microwave radiation causes change in resistance (bolometer) (2) e.g., <ul style="list-style-type: none"> (a) thermistor--as temperature rises, resistance decreases (b) barettter--as temperature rises, resistance rises (3) thermocouple--produces voltage when heated (4) air pressure system--measurement of pressure changes in confined gas when exposed to microwave radiation and heated (5) problem with thermal detection--sensitive to ambient temperature changes <p>e. electrical detectors</p> <ul style="list-style-type: none"> (1) diode or rectifier used to convert RF current into direct current (2) system is extremely sensitive <p>f. except air pressure system, all detectors require antenna (probe) to convert wave RF to wire-conducted RF</p> <ul style="list-style-type: none"> (1) probe--λ specific; however may be able to get with band detector 	

Lesson Outline	
Control of Nonionizing Radiation	Module 6 Unit 1 Lesson 2
TOPIC	REMARKS
<p>(2) when used, must be parallel to field to avoid field disturbance</p> <p>g. instruments usually calibrated for specific use upon purchase</p> <p>5. Measurement taking.</p> <p>a. measure should be taken periodically in any area of potential wave leakage; e.g., wave guides, doors, wave source</p> <p>b. measurements should be taken in all areas of potential exposure, based upon floor plan of work area</p> <p>6. Calculation of exposure.</p> <p>a. done as for UV radiation</p> <p>b. factors</p> <p>(1) exposure</p> <p>(2) time</p> <p>(3) distance (inverse square law)</p> <p>C. Hazard Control</p> <p>1. Hazards best controlled by:</p> <p>a. engineering design</p> <p>(1) location of antennae</p> <p>(2) appropriate shielding</p> <p>b. safe operating procedures</p> <p>2. When surveying for potential hazards, the following should be given consideration as potential hazard sources:</p> <p>a. improper installation</p> <p>(1) poor location</p>	<p>Slide 6.1.2.40.--Hazard Control</p>

Lesson Outline	
Control of Nonionizing Radiation	Module 6 Unit 1 Lesson 2
TOPIC	REMARKS
<ul style="list-style-type: none"> (2) lack of proper grounding of low-frequency supply (3) inadequate or inoperable interlocks, controls, relays, and fuses (4) inadequate shielding of RF areas and circuits b. unsafe operating practices <ul style="list-style-type: none"> (1) unauthorized personnel operating equipment (2) unauthorized adjustment of controls (3) lack of attention while operating equipment (4) reaching into hoppers or conveyors to adjust or extract pieces (5) failure to shut down equipment and report operating defects such as faulty operating sequence, relays that stick, circuit breakers that do not open or close properly, interlocks that fail or are blocked out (6) feeding of brazing or soldering alloys during heating cycle c. faulty maintenance practices <ul style="list-style-type: none"> (1) poor maintenance schedule (2) unauthorized repairmen 	

Lesson Outline	
Control of Nonionizing Radiation	Module 6 Unit 1 Lesson 2
TOPIC	REMARKS
<ul style="list-style-type: none"> (3) failure to shut off power and use lockout procedures before servicing (4) not discharging capacitors (stored-up charge has lethal possibilities) (5) failure to short high-voltage leads to ground before working on equipment (6) improper tools and failure to pick up tools after job (7) lack of final check, after repairs or adjustments have been made, before energizing equipment <p>3. Use of protective clothing is minimized except in special instances.</p> <p>4. Areas of microwave and RF usage should be properly posted.</p> <p>5. Shielding materials and enclosures may be considered; e.g.,</p> <ul style="list-style-type: none"> a. similar principles in shielding as previously described b. e.g., sample attenuation factor <p>D. Summary--Microwaves</p> <ul style="list-style-type: none"> 1. Hazards. 2. Measurement of microwaves 3. Hazard Control <p>IV. Summary</p> <ul style="list-style-type: none"> A. UV Radiation B. Lasers C. Microwaves 	<p>Slide 6.2.1.41.--RF Signs</p> <p>Slide 6.1.2.42.--Shielding Attenuation Factor/ Microwave</p> <p>Ask for questions.</p>

Practice Exercise	
Control of Nonionizing Radiation	Module 6 Unit 1 Lesson 2
<p>1. Referring to the welding shop defined in the Case Study presented in Module 1, Unit 1, Lesson 2, identify</p> <ol style="list-style-type: none"> Potential radiation and nonradiation hazards a plan for measurement and evaluation of potential hazards procedure and equipment use which can be implemented to increase personnel protection. 	
 <p style="text-align: center;">N.T.S.</p>	
Process Description	
<ol style="list-style-type: none"> Parts are delivered to the welding shop by hand truck. Welding is done to specification on cleaned parts. Some of the galvanized parts are sent to welding. Booths #1 and #2 are used for acetylene cutting and welding using an oxygen assist. 	<ol style="list-style-type: none"> Booth #3 used for gas shielded metal arc welding. Carbon dioxide is used as the gas shield. Parts are moved from welding by cart pulled manually or by forklift.

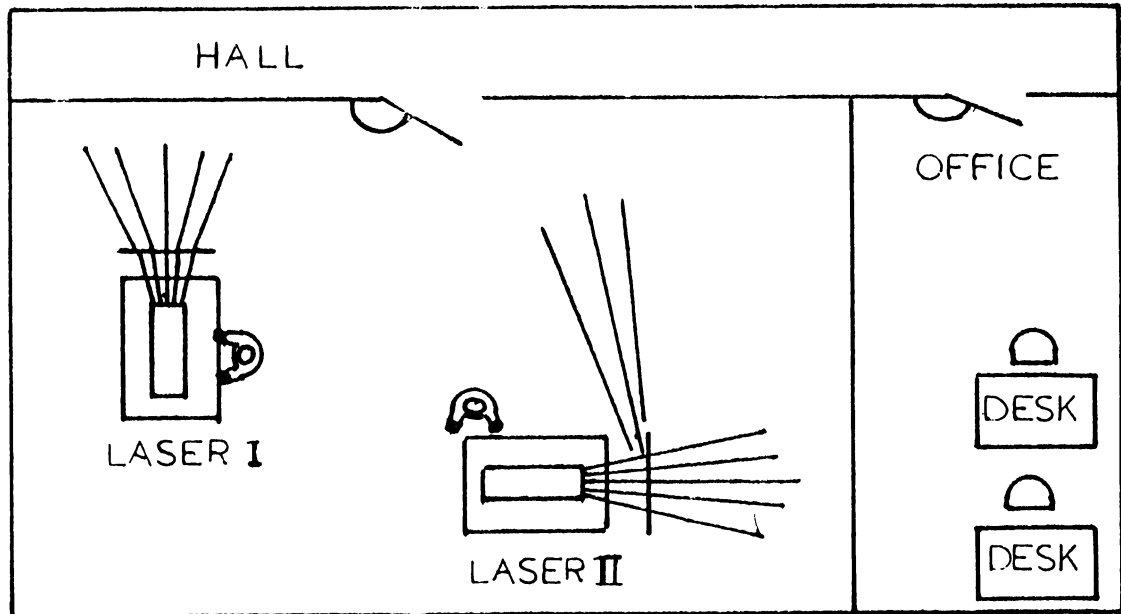
Practice Exercise

Control of Nonionizing Radiation

Module 6

Unit 1

Lesson 2



2. The above facility houses two laser systems. Laser I has been classified as a Class II laser, and the second laser is a Class III laser.
 - a. What potential hazards exist?
 - b. What changes should be made or what protective equipment should be used which would decrease the potential hazard of each of these units, both design and operation?

Title Page	
Ionizing Radiation	Module 6 Unit 2
<div>UNIT 2</div> <div>IONIZING RADIATION</div>	

Performance Objectives		
Lesson	Ionizing Radiation	Module 6 Unit 2
1	1. Given a list of statements, the student will be able to <u>recognize</u> the statement which best defines each of the following: a. atom b. proton c. neutron d. electron e. ion f. isotope	
1	2. For each of the following a. alpha b. beta (positron and negatron) c. gamma d. X-radiation e. neutron the student will be able to <u>recall</u> the following information: (1) type of radiation (particle or photon) (2) charge (+, -, or neutral) (3) atomic weight (nearest amu) (4) relative energy level (5) relative range (6) potential health hazard (7) relative penetrating capability (8) source (machine, radioisotope)	
1	3. Given a list of statements, the student will be able to <u>recognize</u> the statement which best defines: a. half life ($T^{1/2}$) b. radioactive decay c. radioactive decay chain d. daughter products	
1	4. Given the atomic number and weight of a radionuclide (e.g., $(_{92}\text{U}^{232})$ and a list of at least three radioactive emissions (e.g., alpha, positron, gamma), the student will be able to chart the radioactive decay chain and identify the product by number and weight.	
1	5. Given a list of statements, the student will be able to <u>recognize</u> the one(s) that best describe(s) the production of X-radiation.	
1	6. Given the following list of terms: a. electron-volt b. curie c. roentgen d. rad e. rem f. fluence g. flux density the student will be able to <u>recall</u> the correct definition for each.	
1	7. Given the number of disintegrations per second for a radioisotope, the student will be able to calculate the activity of the radioisotope in curies.	

Performance Objectives		
Lesson	Ionizing Radiation	Module 6
		Unit 2
1	8. Given an exposure rate in roentgens or rads, the type of radiation (alpha, beta), and the QF value for each type of radiation, the student will be able to calculate the dose equivalent.	
1	9. Given a list of statements, the student will be able to <u>recognize</u> the one which best defines ionization.	
1	10. Given a list of statements, the student will be able to <u>recognize</u> the one which best describes the lethal dose energy relative to normal cell energy production.	
1	11. Given a list of statements, the student will be able to <u>recognize</u> the one which best describes the difference between the direct and indirect action of radiation.	
1	12. Given a list of statements, the student will be able to <u>recognize</u> the one which best defines <ul style="list-style-type: none"> a. external radiation hazard b. internal radiation hazard and the student will be able to <u>recall</u> one type of radiation which exemplifies each.	
1	13. Given a description of an employee who has received an acute dose of radiation, the student will be able to <u>recall</u> <ul style="list-style-type: none"> a. signs/symptoms of acute whole body radiation b. projected long-term effects of exposure to ionizing radiation. 	
1	14. Given a list of doses (rads), the student will be able to <u>recognize</u> the LD ₅₀ of ionizing radiation.	
1	15. Given an exposure rate (rads or roentgens) for a specified period of time, the QF values, the type of radiation involved, and an MPD table, the student will be able to calculate the dose equivalent and determine if the MPD has been exceeded.	
1	16. The student will be able to <u>recall</u> the definition of <ul style="list-style-type: none"> a. MPD b. MPC 	
1	17. Given a radioactive source with known exposure rate given in dose equivalents, the student will be able to calculate the maximum exposure time for the employee, so that the MPD is not exceeded.	
1	18. The student will be able to <u>recall</u> at least four uses of ionizing radiation. They may include <ul style="list-style-type: none"> a. radiation gauges b. static eliminators c. X-ray analysis d. self-luminous compounds e. tracers 	

Performance Objectives		
Lesson	Ionizing Radiation	Module 6 Unit 2
2	<p>19. Using no references, the student will be able to <u>recall</u> at least three hazards associated with radiation use. The three hazards may be taken from the following list:</p> <ul style="list-style-type: none"> a. direct radiation b. high voltage of associated equipment c. unwanted radiation (e.g., using primarily a beta source which also emits gamma) d. chemical or toxic properties of radionuclide in solution. 	
2	<p>20. Given a list of statements, the student will be able to <u>recognize</u> the statement which best describes the principle of operation of the ionization chamber.</p>	
2	<p>21. Given a list of statements, the student will be able to <u>recognize</u> the one which best describes the difference between air equivalent and tissue equivalent chambers.</p>	
2	<p>22. Given a list of statements, the student will be able to <u>recognize</u> the statement which best describes the operation difference between the ion chamber and the proportional chamber.</p>	
2	<p>23. Given a description of the Geiger-Mueller counter, the student will be able to <u>recall</u> the principle and steps of its operation.</p>	
2	<p>24. Using no references, the student will be able to <u>recall</u></p> <ul style="list-style-type: none"> a. two advantages <ul style="list-style-type: none"> (1) sensitivity (2) portable (3) generally rugged b. two disadvantages <ul style="list-style-type: none"> (1) count not proportional to absorbed dose (2) blocking of readings (3) directional sensitivity <p>of the G-M counter. The advantages/disadvantages must come from the list provided.</p>	
2	<p>25. Given a list of statements, the student will be able to <u>recognize</u> the one which best describes the principles of operation of the</p> <ul style="list-style-type: none"> a. scintillation detector b. photographic device c. thermoluminescent device d. photoluminescent device e. semiconductor device 	

Performance Objectives		
Lesson	Ionizing Radiation	Module 6
		Unit 2
2	<p>26. Given a list of statements, the student will be able to <u>recognize</u> the statement(s) that describe(s)</p> <p>a. advantages</p> <p>b. disadvantages</p> <p>of the use of film badges as a radiation monitoring device.</p>	
2	<p>27. Using no references, the student will be able to <u>recall</u> at least one difference between a pocket dosimeter and a pocket ion chamber.</p>	
2	<p>28. Given a description of a situation which has a potential radiation hazard, a list of the types of radiation involved, and any reference materials, the student will be able to select the appropriate monitoring device (e.g., G-M counter versus proportional counter).</p>	
3	<p>29. Given a list of statements, the student will be able to <u>recognize</u> the one(s) which best describe the responsibilities of the safety professional with respect to radiation protection.</p>	
3	<p>30. Given a list of statements, the student will be able to select the one(s) which best describe(s) the purpose of a radiation safety program.</p>	
3	<p>31. Given a list of statements, the student will be able to <u>recognize</u> the one which best describes the function of "distance" from the source as a protective measure against radiation exposure.</p>	
3	<p>32. Using no references, the student will be able to <u>recall</u> and list at least four responsibilities of the safety professional with respect to the monitoring and control of radiation.</p>	
3	<p>33. Given an exposure rate (rads or R) at a specified distance, the student will be able to calculate the change in exposure rate caused by a specified change in distance.</p>	
3	<p>34. Given a list of statements, the student will be able to select the one which best describes <u>half value layer</u> (HVL).</p>	
3	<p>35. Given the exposure rate, at a specified distance, of a radionuclide, the HVL of the radionuclide, and a table of HVL attenuation coefficients, the student will be able to calculate</p> <p>a. the attenuation caused by a certain thickness of shielding</p> <p>b. the shielding required for a certain attenuation or reduction in exposure rate.</p>	
3	<p>36. Given an exposure rate at a specified time, a half-life attenuation table, and the half-life value for the radionuclide, the student will be able to calculate the change in exposure rate due to a known elapsed time.</p>	

Performance Objectives		
Lesson	Ionizing Radiation	Module 6
		Unit 2
3	37. Given the activity in curies of a known gamma-emitting radionuclide, the energy in MeV, the fraction of disintegrations emitting the energy, and the distance from the source, the student will be able to calculate the absorbed dose in mR/hr.	
3	38. Given the absorbed dose (as calculated above), the student will be able to calculate the effect of modifying <ul style="list-style-type: none"> a. time of exposure b. distance from source c. shielding for gamma emitters.	
3	39. Given <ul style="list-style-type: none"> a. workload--mamp-min/week b. use factor c. occupancy factor d. tube voltage e. distance from source to personnel HVL table for X-radiation, and an Average Radiologic Output Table for X-ray machine, the student will be able to calculate the shielding necessary to meet the MPD value of 0.1 R/hr.	
3	40. Given a list of statements, the student will be able to <u>recognize</u> the one which defines <ul style="list-style-type: none"> a. range b. unit density as used in reference to beta particles.	
3	41. Given the unit density of a specified beta emitter and the density of a shielding material selected, the student will be able to calculate <ul style="list-style-type: none"> a. the attenuation of a given thickness of shielding b. the shielding required to stop all beta particles 	
3	42. Given a list of statements, the student will be able to <u>recognize</u> the one which best describes why light elements are used to shield beta emitters.	
3	43. Given a list of statements, the student will be able to <u>recognize</u> the one which best describes the danger involved with alpha emitters.	
3	44. Given the hydrogen density of a material, a table or graph of hydrogen attenuation coefficients, and the formula for calculating HVL, the student will be able to calculate the HVL value for a neutron for a specified energy level.	

Performance Objectives		
Lesson	Ionizing Radiation	Module 6
		Unit 2
3	45. Given a description of a situation describing the use of a known radiation source and the protective measures taken, the student will be able to determine if the protective measures are adequate and the steps necessary to correct any deficiencies.	
3	46. Given a description of a radiation area, the student will be able to <u>recall</u> and list the procedure for making routine measurements, including the components of an operations analysis.	
3	47. Given a list of statements, the student will be able to recognize the one which best describes the procedure for <ul style="list-style-type: none"> a. smear (wipe) test for surface contamination b. air analysis c. water sample analysis 	
3	48. Given a description of a procedure involving radiation and an employee's activities when working with the radiation source, the student will be able to determine the proper location for the placement of personnel monitors.	
3	49. Given a description of a facility using radioisotopes with a potential for contamination, the student will be able to identify potential problems in the design of the facility. These problems may include: <ul style="list-style-type: none"> a. inadequate shielding b. rough, porous working surfaces c. dust collecting areas; including suspended lights and pipes, roof trusses d. nonenclosed shelving e. poor construction, causing potential leakage f. inavailability of special handling equipment g. inadequate or inappropriate heat and exhaust system design h. insufficient containment procedures; e.g., glove box 	
3	50. Given a description of a radiation area, including the level of radiation involved and any references selected by the student, the student will be able to select the appropriate radiation warning signs for that area.	
3	51. Given the amount and type of radioactivity involved, the air/water flow of the given system, and Handbook #69, the student will be able to calculate the maximum radioactive waste which can be disposed of by <ul style="list-style-type: none"> a. release into the air b. release into tidal waters or sewage system c. incineration 	

Performance Objectives		
Lesson	Ionizing Radiation	Module 6
		Unit 2
3	52. Given the amount and type of radioactivity involved and the NRC limits for burial procedures, the student will be able to calculate what percent of the radioisotope may be disposed of by burial.	
3	53. Given no references, the student will be able to <u>recall</u> the primary differences between shielding garments and protective clothing.	
3	54. Given a list of statements, the student will be able to <u>recognize</u> the one(s) which best describe the purpose and components of <ul style="list-style-type: none"> a. pre-employment medical examinations b. periodic medical examinations c. follow-up examinations 	
3	55. Given a list of statements, the student will be able to recognize the one which best describes the procedure for decontamination of personnel and facilities.	

Unit Activities--Instructor	
Ionizing Radiation	Module 6 Unit 2
<p>In order to present the unit material to the students, the instructor is responsible for the following:</p> <p><u>Lesson 1--Principles of Ionizing Radiation</u></p> <p><u>Classroom Presentation</u></p> <p>Present a lecture related to the physics and chemistry of ionizing radiation. The lecture should emphasize the properties and characteristics of alpha, beta, gamma, X-, and neutron radiation. Also, the lecture is designed to present such topics as common units of radiation measure, biological effects of radiation, established exposure limits, and common applications. By the completion of this lesson, the student should have a basic understanding of the principles of ionizing radiation.</p> <p><u>Time Allotted</u></p> <p>2 Hours</p> <p><u>Demonstrations</u></p> <p>No demonstrations are required.</p> <p><u>Supervised Practice</u></p> <p>No supervised practice is required.</p>	

Unit Activities--Instructor	
Ionizing Radiation	Module 6 Unit 2
<p><u>Lesson 2--Monitoring Instrumentation</u></p> <p><u>Classroom Presentation</u></p> <p>This lesson is designed to provide an overview of the principles, operation, and use of basic ionizing radiation monitoring instrumentation. The instructor should provide each student with the opportunity to examine each piece of equipment. Time is not allotted in this lesson to allow a practical application demonstration of each instrument.</p> <p><u>Time Allotted</u></p> <p>1 Hour</p> <p><u>Demonstrations</u></p> <p>The instructor should briefly demonstrate the use of</p> <ol style="list-style-type: none"> 1. ionization chamber 2. proportional chamber 3. Geiger-Mueller counter 4. scintillation detectors 5. film badges 6. pocket dosimeter 7. pocket ion chamber <p>The demonstration should include a brief description of the instruments, including</p> <ol style="list-style-type: none"> a. components of the instrument b. primary use c. range and type of radiation which can be monitored d. meter readings, range, unit e. adaptation required for different types of radiation f. steps for use <p><u>Supervised Practice</u></p> <p>Time is not allotted for supervised practice, but each student should be given an opportunity to examine the equipment.</p>	

Unit Activities--Instructor	
Ionizing Radiation	Module 6 Unit 2
<u>Lesson 3--Control of Ionizing Radiation</u> <u>Classroom Presentation</u> Present a lecture concerning the monitoring and control of ionizing radiation, including such things as shielding requirements, facilities design, and decontamination procedure. <u>Time Allotted</u> 2 Hours <u>Demonstrations</u> No demonstrations are required. <u>Supervised Practice</u> No supervised practice is required.	

Unit Activities--Student																																
Ionizing Radiation	Module 6 Unit 2																															
<p>In order to complete the unit successfully, the student will be responsible for the following:</p> <p><u>Lesson 1--Principles of Ionizing Radiation</u></p> <p><u>Classroom Activity</u></p> <p>Attend a 2-hour lecture related to the physics and chemistry of ionizing radiation. By the end of the lesson, the student should have a basic understanding of the principles of ionizing radiation.</p> <p><u>Assignment</u></p> <p>The student should review the following materials prior to attending class.</p> <table border="1" style="width: 100%; border-collapse: collapse; margin-top: 10px;"> <thead> <tr> <th style="width: 60%; padding: 5px;">READING</th> <th style="width: 20%; padding: 5px;">SHORT COURSE</th> <th style="width: 20%; padding: 5px;">EXTENDED 1-HOUR</th> </tr> </thead> <tbody> <tr> <td style="padding: 5px;">Industrial Hygiene Engineering and Control</td> <td style="padding: 5px;"></td> <td style="padding: 5px;">Section 6 Chapter 3</td> </tr> <tr> <td style="padding: 5px;">the Industrial Environment--its Evaluation and Control</td> <td style="padding: 5px;"></td> <td style="padding: 5px;">Chapter 29</td> </tr> <tr> <td style="padding: 5px;"></td> <td style="padding: 5px;"></td> <td style="padding: 5px;"></td> </tr> <tr> <td style="padding: 5px;"></td> <td style="padding: 5px;"></td> <td style="padding: 5px;"></td> </tr> <tr> <td style="padding: 5px;"></td> <td style="padding: 5px;"></td> <td style="padding: 5px;"></td> </tr> <tr> <td style="padding: 5px; text-align: center;">PROBLEMS</td> <td style="padding: 5px;"></td> <td style="padding: 5px;"></td> </tr> <tr> <td style="padding: 5px;">Practice Exercises</td> <td style="padding: 5px;"></td> <td style="padding: 5px;">Section 6 Chapter 2</td> </tr> <tr> <td style="padding: 5px;"></td> <td style="padding: 5px;"></td> <td style="padding: 5px;"></td> </tr> <tr> <td style="padding: 5px;"></td> <td style="padding: 5px;"></td> <td style="padding: 5px;"></td> </tr> </tbody> </table>			READING	SHORT COURSE	EXTENDED 1-HOUR	Industrial Hygiene Engineering and Control		Section 6 Chapter 3	the Industrial Environment--its Evaluation and Control		Chapter 29										PROBLEMS			Practice Exercises		Section 6 Chapter 2						
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Unit Activities--Student																																
Ionizing Radiation	Module 6 Unit 2																															
<p>In order to complete the unit successfully, the student will be responsible for the following:</p> <p><u>Lesson 2--Monitoring Instrumentation</u></p> <p><u>Classroom Activity</u></p> <p>Attend a one-hour lecture on the principles, operation, and use of basic ionizing radiation monitoring instrumentation.</p> <p><u>Assignment</u></p> <p>The student should review the following materials prior to attending class.</p> <table border="1" style="width: 100%; border-collapse: collapse; margin-top: 10px;"> <thead> <tr> <th style="width: 60%; padding: 5px;">READING</th> <th style="width: 20%; padding: 5px;">SHORT COURSE</th> <th style="width: 20%; padding: 5px;">EXTENDED 1-HOUR</th> </tr> </thead> <tbody> <tr> <td style="padding: 5px;">Industrial Hygiene Engineering and Control</td> <td></td> <td style="padding: 5px;">Section 6 Chapter 4</td> </tr> <tr><td style="height: 40px;"></td><td></td><td></td></tr> <tr><td style="height: 40px;"></td><td></td><td></td></tr> <tr><td style="height: 40px;"></td><td></td><td></td></tr> <tr><td style="height: 40px;"></td><td></td><td></td></tr> <tr> <td style="padding: 5px; text-align: center;">PROBLEMS</td> <td></td> <td></td> </tr> <tr> <td style="padding: 5px;">Industrial Hygiene Engineering and Control</td> <td></td> <td style="padding: 5px;">Section 6 Chapter 3</td> </tr> <tr><td style="height: 40px;"></td><td></td><td></td></tr> <tr><td style="height: 40px;"></td><td></td><td></td></tr> </tbody> </table>			READING	SHORT COURSE	EXTENDED 1-HOUR	Industrial Hygiene Engineering and Control		Section 6 Chapter 4													PROBLEMS			Industrial Hygiene Engineering and Control		Section 6 Chapter 3						
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Unit Activities--Student

Ionizing Radiation

Module 6

Unit 2

In order to complete the unit successfully, the student will be responsible for the following:

Lesson 3--Control of Ionizing Radiation

Classroom Activity

Attend a two-hour lecture on the monitoring and control of ionizing radiation.

Assignment

The student should review the following materials prior to attending class.

READING	SHORT COURSE	EXTENDED 1-HOUR
Industrial Hygiene Engineering and Control		Section 6 Chapter 5
PROBLEMS		

Facilities, Equipment, and Materials

Ionizing Radiation

Module 6

Unit 2

Facilities

Lecture--Normal Classroom

Equipment and Materials

Educational

Chalkboard

Chalk

Eraser

35 mm Projector with remote control

Screen

Health and Safety

Ionization chamber

Proportional counter

Geiger-Mueller counter

Scintillation detector

Film badges

Pocket dosimeter

Pocket ion chamber

Visuals

Slide Series--Industrial Hygiene Engineering and Control
Module 6, Unit 2

References Used in Class

Industrial Hygiene Engineering and Control

the Industrial Environment--its Evaluation and Control

"Threshold Limit Values for Chemical Substances and Physical Agents
In the Workroom Environment with Intended Changes for 1976"

"Maximum Permissible Body Burdens and Maximum Permissible Concentra-
tions of Radionuclides in Air and Water for Occupational Exposure,"
Handbook 69

Lesson Outline	
Principles of Ionizing Radiation	Module 6 Unit 2 Lesson 1
TOPIC	REMARKS
<p>I. Ionizing Radiation--Introduction</p> <p>A. Atomic Structure</p> <ol style="list-style-type: none"> 1. There exist over 100 elements; the basic ingredient in all materials. 2. Atom--smallest particle of an element which possesses chemical properties of that element. 3. Atom--composed of three fundamental particles. <ol style="list-style-type: none"> a. proton--positive charge (+1) and mass of 1 atomic mass unit (amu) b. neutron--no charge and mass of 1 amu c. electron--negative charge (-1); mass of 5.43×10^{-4} amu 4. Protons and neutrons contribute most of mass and make up the nucleus. 5. Electrons exist in orbits around the nucleus. 6. Undisturbed atom will have equal numbers of protons and electrons--electrically neutral. 7. Atom with surplus or deficit of orbital electrons--positively or negatively charged--called an <u>ion</u>. <p>II. Radioactivity</p> <ol style="list-style-type: none"> A. For a given number of protons, nuclear stability exists with a certain number of neutrons. B. Atoms with same number of protons, but different neutrons, are called <u>isotopes</u>. C. Radioactivity--Improper (unstable) combination of protons and neutrons in the nucleus. 	<p>If necessary, review with the students the differences between ionizing and nonionizing radiation</p> <p>This section is provided as a review. It may be deleted at the instructor's discretion.</p> <p>Slide 6.2.1.1.--Components of an Atom</p> <p>Slide 6.2.1.2.--Nuclides of Hydrogen</p> <p>Use hydrogen as an example of isotope.</p>

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<p>D. Atoms will spontaneously transform to more stable state; radiation emitted in form of:</p> <ol style="list-style-type: none"> 1. Alpha particles 2. Beta particles 3. Gamma radiation 4. Combination of the above. <p>E. Alpha Particles</p> <ol style="list-style-type: none"> 1. Originate in the nucleus of radioactive atom. 2. Composed of 2 protons and 2 neutrons (helium nucleus). 3. Mass of 4 amu and a charge of +2. 4. When emitted, new element formed; atomic number decreases by 2 and atomic weight decreases by 4. 5. Energy of alpha dependent upon radionuclide source; may occur up to 10 MeV. 6. Cause more ionization than beta or gamma radiation, but travel much shorter distance. 7. Range. <ol style="list-style-type: none"> a. range short because of high mass and large charge b. general range of alpha particles in air is approximately 4 inches. c. can be stopped by a film of water, sheet of paper, or other paper-thin materials. 8. Sources. <ol style="list-style-type: none"> a. radioactive decay b. e.g., ${}_{90}\text{Th}^{232}$, ${}_{92}\text{U}^{238}$ 9. Interaction with target--attract two electrons to form helium atom (direct ionization). 	<p>Slide 6.2.1.3.--Alpha Particles</p> <p>Ask students if there is a potential hazard with alpha particles if the range is short and stopped by paper.</p> <p>Slide 6.2.1.4.--Relative Penetrating Capability of Alpha Particles</p> <p>Refer to sample decay chain presented later.</p> <p>Slide 6.2.1.5.--Interaction of Alpha Particles</p>

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<ul style="list-style-type: none"> d. can be stopped by material of low atomic weight; e.g., aluminum 6. Sources. <ul style="list-style-type: none"> a. radioactive decay b. e.g., ${}_{92}\text{U}^{232}$ 7. Interaction with target--direct ionization. <ul style="list-style-type: none"> a. generally causes ionization b. positron--formation of gamma radiation c. negatron--formation of X-radiation G. Gamma (γ) Radiation <ul style="list-style-type: none"> 1. Electromagnetic radiation. 2. Originates from nucleus but emission does not cause change in element properties. 3. Energy level. <ul style="list-style-type: none"> a. highest electromagnetic radiation to be discussed b. dependent upon radio-nuclide source c. 0.15 to several MeV 4. Source. <ul style="list-style-type: none"> a. radioactive decay b. e.g., ${}_{92}\text{U}^{238}$ c. positron destruction. 5. Penetration. <ul style="list-style-type: none"> a. deep penetration; tremendous health problem b. No mass or charge c. e.g., half value layer for 1 MeV of gamma radiation is equal to 0.5 inches of steel 	<p>Refer to sample decay chain.</p> <p>Slide 6.2.1.8.--Beta Particle Interaction</p> <p>Slide 6.2.1.9.--Gamma Radiation</p> <p>Refer to sample decay chain.</p> <p>Slide 6.2.1.10.--Relative Penetrating Capability of Gamma Radiation</p>

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<p>6. Interaction with target--indirect ionization.</p> <p>a. photoelectric effect--incident photons cause ejection of orbital electrons with energy equal to difference between photon energy and electron binding energy--X-radiation or electrons emitted as shell vacancies corrected</p> <p>b. Compton effect--photon gives up part of energy to orbital electrons--electron recoils and may be ejected; degraded photon created.</p> <p>c. pair production</p> <p>(1) high energy photon interacts with electric field surrounding charged particle (nucleus)</p> <p>(2) causes formation of electron and positron of equal energy</p> <p>(3) X- and gamma radiation formed when positron and negatron collide or slow</p> <p>H. Over forty elements in nature which undergo this process.</p> <p>I. Decay Process</p> <p>1. Radioactive materials are unstable because of energy involved; e.g.,</p> <p>a. repulsion of positively charged protons in a confined space</p> <p>b. interaction of neutrons with protons</p>	Slide 6.2.1.11.--Gamma Interaction

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<ul style="list-style-type: none"> 2. Isotope releases energy in an effort to find more stable level. 3. Depending upon type of emission, element may change; e.g., <ul style="list-style-type: none"> a. alpha--new element b. beta--new element c. neutron--same element, new isotope d. gamma--same element 4. Sample decay chain. <ul style="list-style-type: none"> a. radionuclides decay into other radionuclides b. radionuclides form "daughter" products c. total radioactivity may increase because of presence of "daughter" products 5. Total of approximately 240 such radionuclides. 6. Number of atoms decaying proportional to number of atoms present. <ul style="list-style-type: none"> a. constant for any radionuclide b. constant fraction disintegration per unit time c. e.g., half-life scheme ($T_{1/2}$); if $T_{1/2}$ is long, radiation released is small 	<p>Slide 6.2.1.12.--Uranium-238 Decay Chain</p> <p>Inform students of the relative hazard of each.</p> <p>Slide 6.2.1.13.--Relative Hazard of Nuclides</p> <p>Slide 6.2.1.14.--Half-Life Decay Series</p> <p>Describe half-life scheme to students.</p>
III. Radiation--Other Sources	
<ul style="list-style-type: none"> A. Two other types of radiation formed from some type of atomic activity. <ul style="list-style-type: none"> 1. X-radiation (electron movement). 2. Neutrons (fission). 	

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<ul style="list-style-type: none"> <ul style="list-style-type: none"> b. fission of isotopes of uranium and plutonium caused by neutron bombardment produces more neutrons 2. Has a mass of 1 amu and a charge of 0. 3. Sources. <ul style="list-style-type: none"> a. nuclear reaction (described above) b. accelerators <ul style="list-style-type: none"> (1) Van de Graaf (2) Cockroft-Walton generator 4. Penetrating capability. <ul style="list-style-type: none"> a. dependent upon <ul style="list-style-type: none"> (1) energy level (2) characteristics of medium (3) type of collision b. mean free path (mfp) <ul style="list-style-type: none"> (1) average distance a neutron of given energy will travel (2) probability of interaction in 3 mfp = 0.95 (3) e.g., in human tissue, mfp = 0.25 to several inches 5. Interaction with target. <ul style="list-style-type: none"> a. fast neutrons--collide with nuclei and lose energy (billiard ball-like collision) b. slow (thermal)--captured by absorber nuclei c. in either case, alpha, beta, or gamma radiation is emitted 	<p>Describe briefly the principle of chain reaction.</p> <p>At instructor discretion, the general principles and operation of an accelerator may be presented</p> <p>Slide 6.2.1.19.--Relative Penetrating Capability of Neutrons</p> <p>Review penetrating capability of each type of radiation.</p> <p>Slide 6.2.1.20.--Neutron Interaction</p>

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<p>d. because ionization is secondary to neutron interaction, calculation of neutron dose is difficult</p> <p>D. Summary</p> <p>IV. Units of Measure</p> <p>A. Units of Energy</p> <ol style="list-style-type: none"> 1. Joule--standard unit of energy in physics. 2. erg--1.0×10^{-7} joules. 3. Electron volt (ev). <ol style="list-style-type: none"> a. energy unit of atomic and nuclear activity b. equal to kinetic energy acquired by an electron after being accelerated through potential difference of one volt 4. Energies encountered expressed as <ol style="list-style-type: none"> a. Kev--thousands of electron volts b. MeV--millions of electron volts c. e.g., energy of $^{137}_{55}\text{Cs}$ gamma radiation is 0.667 MeV. 	<p>Slide 6.2.1.21.--Properties of Ionizing Radiation</p> <p>Review properties of five types of radiation discussed, including</p> <ol style="list-style-type: none"> a. source b. description c. energy d. hazard e. necessary shielding (based upon penetrating capability) <p>The students should understand the terms presented. Emphasis should be placed on the concept of each term rather than the <u>numerical value</u>.</p> <p>Slide 6.2.1.22.--Units of Energy</p>

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<ul style="list-style-type: none"> 5. Conversion-- 1.602×10^{-13} J/MeV 6. Energies associated with emission have been calculated and are available in reference manuals. 	
<ul style="list-style-type: none"> B. Units of Activity <ul style="list-style-type: none"> 1. Activity--rate of radioactive decay in a given sample (dn/dt). 2. Curie (Ci). <ul style="list-style-type: none"> a. unit of activity b. disintegration (counts) per second (minutes) c. $1 \text{ Ci} = 3.7 \times 10^{10}$ 3. Unit of activity can be correlated to potential exposure. 	Slide 6.2.1.23.--Units of Activity
<ul style="list-style-type: none"> C. Exposure. <ul style="list-style-type: none"> 1. Roentgen (R)--unit of exposure 2. Measures amount of charge produced in air by gamma or X-ray photon. 3. $1\text{R} = 2.58 \times 10^{-4}$ coulombs/Kg air. 4. 1R produces 2×10^9 ion pairs in air. 5. <u>Exposure rate</u>. <ul style="list-style-type: none"> a. time derivative of exposure b. expressed "R/hr" 	Slide 6.2.1.24.--Units of Exposure
<ul style="list-style-type: none"> D. Absorbed Dose <ul style="list-style-type: none"> 1. Energy imparted by ionizing radiation to matter per unit mass of absorber. 2. <u>rad</u>--standard unit of absorbed dose. 3. $1 \text{ rad} = 10^{-2}$ joule/Kg 	Slide 6.2.1.25.--Units of Absorbed Dose

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<p>4. <u>Dose rate.</u></p> <p>a. time derivative of absorbed dose.</p> <p>b. expressed "mrad/hr"</p> <p>E. Dose Equivalent</p> <p>1. Measure of exposure and absorbed dose does not consider</p> <p>a. spatial distribution of absorbed energy</p> <p>b. type of ionizing radiation</p> <p>c. radionuclide source; e.g., certain radionuclides migrate to certain areas of the body</p> <p>2. <u>rem.</u></p> <p>a. standard unit of dose equivalent</p> <p>b. takes into consideration the above-mentioned factors</p> <p>c. generally</p> <p>$\text{rem} = \text{rad} \times \text{QF}$</p> <p><u>Practical Quality Factors</u></p> <p><u>Radiation Type</u></p>	<p>Slide 6.2.1.26.--Unit of Dose Equivalent</p>														
<p style="text-align: right;">Rounded QF</p> <table> <tr> <td>X-rays, gamma rays, electrons or positrons, Energy > 0.03 MeV</td><td>1</td></tr> <tr> <td>Electrons or positrons, Energy < 0.03 MeV</td><td>1</td></tr> <tr> <td>Neutrons, Energy < 10 keV</td><td>3</td></tr> <tr> <td>Neutrons, Energy > 10 KeV</td><td>10</td></tr> <tr> <td>Protons</td><td>10</td></tr> <tr> <td>Alpha Particles</td><td>20</td></tr> <tr> <td>Fission fragments, recoil nuclei</td><td>20</td></tr> </table>	X-rays, gamma rays, electrons or positrons, Energy > 0.03 MeV	1	Electrons or positrons, Energy < 0.03 MeV	1	Neutrons, Energy < 10 keV	3	Neutrons, Energy > 10 KeV	10	Protons	10	Alpha Particles	20	Fission fragments, recoil nuclei	20	<p>Slide 6.1.2.27.--QF Values</p>
X-rays, gamma rays, electrons or positrons, Energy > 0.03 MeV	1														
Electrons or positrons, Energy < 0.03 MeV	1														
Neutrons, Energy < 10 keV	3														
Neutrons, Energy > 10 KeV	10														
Protons	10														
Alpha Particles	20														
Fission fragments, recoil nuclei	20														

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<p>d. dose equivalents used in personnel dose monitoring; also basis for maximum permissible dose (MPD)</p> <p>e. example--</p> <p>Alpha source with reading of 0.05 mrad/hr.</p> <p>Calculate rem value for the 8-hr period.</p> <p><u>Solution</u></p> $\text{rem} = \text{rad} \times \text{QF}$ $\text{rem} = \frac{0.05 \text{ mrad}}{\text{hr}} \times \frac{20 \text{ mrem}}{\text{mrad}}$ $= \frac{1.0 \text{ mrem}}{\text{hr}}$ $\frac{\text{Exposure}}{8 \text{ hr}} = \frac{1.0 \text{ mrem}}{\text{hr}} \times 8 \text{ hr} = 8.0 \text{ mrem}$ <p>F. Fluence (Φ)</p> <ol style="list-style-type: none"> 1. Number of particles which enter a sphere of unit cross sectional area. 2. Expressed in terms of "particles per cm^2." 3. <u>Energy fluence (Ψ)</u>. <ol style="list-style-type: none"> a. sum of energy of particles b. expressed in terms of "MeV/cm^2" <p>G. Flux Density (ϕ)</p> <ol style="list-style-type: none"> 1. Increment of particle fluence per unit time ($\phi = d\Phi/dt$) 2. Expressed "$\text{particles}/\text{cm}^2/\text{sec}$" 3. e.g., neutrons/cm^2/sec. 4. <u>Energy flux density</u>. <ol style="list-style-type: none"> a. time derivative of energy fluence b. expressed "$\text{MeV}/\text{cm}^2/\text{sec}$" 	<p>Slide 6.2.1.28.--Calculation of Dose Equivalent--Question</p> <p>Slide 6.2.1.29.--Calculation of Dose Equivalent--Solution</p> <p>Slide 6.2.1.30.--Fluence</p> <p>Inform the students that fluence and flux density are presented because they are often presented in the literature.</p> <p>Slide 6.2.1.31.--Flux Density</p>

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<ul style="list-style-type: none"> 4. Generally, radiation causes <ul style="list-style-type: none"> a. cell death b. cell damage which prevents growth or causes formation of cell mutation c. cell function and ultimately body function reduced D. Relative Biological Efficiency <ul style="list-style-type: none"> 1. All forms of ionizing radiation produce some type of injury. 2. Production of tissue reaction dependent upon density of ionization in the radiation path; i.e., linear energy transfer. 3. Linear energy transfer. <ul style="list-style-type: none"> a. related to amount of energy transferred to medium per linear penetration b. e.g., alpha particle disseminates high energy over short penetrating distance ∴ high energy transfer 4. Particulate radiation (alpha, neutrons) produces more damage per energy absorbed; thus high relative biological efficiency (RBE). 5. Electromagnetic radiation causes more diffuse ionization. E. Types of Exposures <ul style="list-style-type: none"> 1. External <ul style="list-style-type: none"> a. radiation permeates skin b. e.g., gamma and X-radiation 	<p>Slide 6.1.2.34.--Types of Exposure</p>

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<ul style="list-style-type: none"> 2. Internal. <ul style="list-style-type: none"> a. radiation source enters through <ul style="list-style-type: none"> (1) respiratory system (2) digestive system (3) open cut b. e.g., alpha particles c. radioactive source in body emitting radiation d. effective dose difficult to calculate 3. Biological effect the same, but internal exposure may be more devastating. <p>F. Radiation Pathology</p> <ul style="list-style-type: none"> 1. Response of individual to radiation depends on <ul style="list-style-type: none"> a. dosage b. amount and type of tissue irradiated; e.g., localized damage vs. whole body irradiation 2. Local exposure. <ul style="list-style-type: none"> a. causes damage to specific site or organ b. systemic changes may occur 3. Whole body radiation. <ul style="list-style-type: none"> a. dose greater than 100 rad causes systemic illnesses (acute radiation syndrome) b. signs/symptoms <ul style="list-style-type: none"> (1) nausea and vomiting (2) skin erythema (3) intestinal bleeding and diarrhea (4) gradual loss of hair 	<p>Slide 6.2.1.35.--Radiation Pathology</p>

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<p>c. because of cell damage, cerebral edema may occur and cause death within minutes to hours</p> <p>4. The following effects would be observed in man after acute whole body doses of penetrating radiation.</p> <p>0-25 rad -no observable effect.</p> <p>25-50 rad -minor temporary blood changes.</p> <p>50-150 rad -possible nausea and vomiting along with reduce white blood cell count.</p> <p>150-300 rad -exaggeration of above symptoms plus diarrhea, malaise, and loss of appetite.</p> <p>300-500 rad -exaggeration of above symptoms, plus hemorrhaging and loss of hair (epilation). About 50% of the untreated exposed population will die at 450-500 rad level.</p> <p>Above 500 rad-most of the above symptoms will appear sooner and in more severe form. Survival chances diminish rapidly with higher doses.</p> <p>5. Long-term effects.</p> <p>a. cancer</p> <p>b. general body deterioration (early aging)</p> <p>c. loss of hair</p> <p>d. mutation of genes (deformed offspring)</p>	<p>Slide 6.2.1.36.--Acute Radiation Syndrome</p> <p>Slide 6.2.1.37.--Long-Term Effects of Ionizing Radiation</p>

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<p>VI. Ionizing Radiation--Application</p> <p>A. Radioisotopes Available in</p> <ol style="list-style-type: none"> 1. Naturally occurring radionuclides. 2. Nuclides produced by accelerators. 3. Fission products. <p>B. Industrial Uses</p> <ol style="list-style-type: none"> 1. Radiation gauges. <ol style="list-style-type: none"> a. radiation penetrates or is reflected off matter--can determine useful information if reading can be taken. b. because radiation level low, use is nondestructive c. radiation gauges used to monitor automated product lines <ol style="list-style-type: none"> (1) determine sheet metal thickness (2) density of metals or fluids (3) moisture content 	<p>Because of overlapping of the various types of ionizing radiation, the general industrial and medical uses will be discussed rather than the uses for each specific type of radiation.</p> <p>Students should be asked to describe</p> <ol style="list-style-type: none"> 1. examples of uses of ionizing radiation 2. description of application and work environment <p>they may be familiar with.</p> <p>Ask students for uses of radiation gauges.</p> <p>Slide 6.2.1.38.--Radiation Gauge Efficiency</p> <p>Briefly review data on slide to show students increased sensitivity radiation gauges.</p>

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<ul style="list-style-type: none"> d. types of gauges <ul style="list-style-type: none"> (1) transmission--monitors radiation penetrating substance (2) reflection--monitors radiation reflected e. type of ionizing radiation commonly used in gauges <ul style="list-style-type: none"> (1) X-radiation (2) gamma radiation $^{55}\text{Cs}^{137}$ (3) beta (negatrons) $^{38}\text{Sr}^{90}$ (4) neutrons 	Slide 6.2.1.39.--Radiation Gauge--Schematic
<ul style="list-style-type: none"> 2. Radiography and fluoroscopy. <ul style="list-style-type: none"> a. defined as production of a shadow image of the internal structure of an object b. type of radiation used <ul style="list-style-type: none"> (1) X-radiation (2) gamma radiation (3) neutrons c. radiography <ul style="list-style-type: none"> (1) shadow image recorded permanently on film (2) higher quality and better resolution than fluoroscopy d. fluoroscopy--shadow image presented temporarily on a screen e. used for quality control of a process, e.g., <ul style="list-style-type: none"> (1) welded joints (2) seams--pipelines, etc. 	Slide 6.2.1.39.--Radiation Uses Ask students to give practical example of radiography.

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3. Static eliminator. <ul style="list-style-type: none"> a. primarily alpha emitter used b. used on sheet process--removes static c. unshielded source used d. must be shielded from personnel 	Slide 6.2.1.40.--Radiation Uses
4. X-ray diffraction and fluorescent analysis. <ul style="list-style-type: none"> a. planes in a molecular crystal lattice will diffract X-radiation in a set pattern b. can be used to determine crystal state of material c. can be used to determine actual content of material because of absorption and emission properties 	Slide 6.2.1.41.--Radiation Uses
5. Electron beam equipment. <ul style="list-style-type: none"> a. electron beam evaporator <ul style="list-style-type: none"> (1) evaporates target substance (2) evaporates substance used as coatings on glass, plastic, etc. b. electron beam welder <ul style="list-style-type: none"> (1) similar to evaporator only higher energy levels (2) value <ul style="list-style-type: none"> -high spot intensity -welded parts not contaminated by atmosphere 	Slide 6.2.1.42.--Radiation Uses

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<ul style="list-style-type: none"> c. electron microscope <ul style="list-style-type: none"> (1) high resolution (2) used by metallurgists, solid state technologists (3) specialists required to operate equipment d. primary radiation danger--X-radiation 6. Activation analysis. <ul style="list-style-type: none"> a. method of determining concentration of elements in a given compound b. element bombarded, and radiation emitted by excited nuclei is measured c. each radionuclide has distinct pattern of X- and gamma radiation emission 7. Radioactive tracers--"tagging." <ul style="list-style-type: none"> a. basic uses <ul style="list-style-type: none"> (1) study basic physical phenomenon (2) measure yield in chemical separation (3) make volume determination (4) "tag" for products in transit b. e.g., <ul style="list-style-type: none"> (1) irradiate piston ring and monitor wear by autoradiography (2) flow of petroleum products through pipes tagged for volume determination 	Slide 6.2.1.43.--Radiation Uses

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<ul style="list-style-type: none"> 8. Fire detectors--function with ionization chambers requiring small radioactive source. 9. Self-luminous compounds. <ul style="list-style-type: none"> a. illumination of dials b. process <ul style="list-style-type: none"> (1) compound of phosphor (zinc sulfide) and radionuclide prepared (2) bombardment of phosphor with ionizing particles causes the phosphor to scintillate causing it "to glow" 10. Large radiation sources. <ul style="list-style-type: none"> a. radiation processing <ul style="list-style-type: none"> (1) use of ionizing radiation to produce biological or chemical effect (2) e.g., sterilization of medical supplies, synthesis of ethyl bromide b. thermoelectric generators <ul style="list-style-type: none"> (1) radiation used as heat source (2) thermoelectric converters convert heat to electricity (3) must be shielded because of gamma and X-radiation and neutrons produced c. nuclear explosives C. Agricultural Uses <ul style="list-style-type: none"> 1. Used in basically two ways. <ul style="list-style-type: none"> a. irradiation 	<ul style="list-style-type: none"> Slide 6.2.1.45.--Radiation Uses Slide 6.2.1.46.--Radiation Uses Slide 6.2.1.47.--Radiation Uses Slide 6.2.1.48.--Radiation Uses--Agricultural

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<ul style="list-style-type: none"> <ul style="list-style-type: none"> b. radiotracers--isotopes same, whether radioactive or not 2. Irradiation. <ul style="list-style-type: none"> a. makes use of modification of matter by radiation b. all types of radiation used in agriculture <ul style="list-style-type: none"> (1) alpha--to study cellular disposition (2) beta--evaluation of metabolic processes, pathways of fertilizer and nutrient disposition (3) X- and gamma radiation--similar uses as beta emitters; more problems because of higher energy levels D. Medical Uses <ul style="list-style-type: none"> 1. X-ray applications <ul style="list-style-type: none"> a. development of film of outline of bones, teeth, and calcified structures b. injection or ingestion of X-ray opaque substances to provide outlines of organ--e.g., barium sulfate ingested to provide film of intestinal tract 2. Irradiation--destruction of diseased cells; e.g., carcinoma. 3. Use of radionuclides. <ul style="list-style-type: none"> a. radioactive isotopes of appropriate elements introduced and disposition traced throughout body or to specific organs 	<p>Slide 6.2.1.49.--Radiation Uses-- Medical</p>

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Principles of Ionizing Radiation	Module 6 Unit 2 Lesson 1
TOPIC	REMARKS
<p>D. Maximum Permissible Concentration that would lead to exceeding MPD calculated by--</p> <ol style="list-style-type: none"> 1. Type of radionuclide. 2. Area of Exposure <p>VIII. Summary--Discussed Thus Far</p> <ol style="list-style-type: none"> A. Atomic Structure B. Radioactivity C. Specific types of ionizing radiation <ol style="list-style-type: none"> 1. Alpha 2. Beta 3. Gamma 4. X-radiation 5. Neutrons D. Units of Measure E. Biological Effects F. Application/Hazards G. Maximum Permissible Dose 	<p>Slide 6.2.1.52.--MPC Equivalents</p> <p>If available, show students NBS Handbook #69, "Maximum Permissible Body Burden and Maximum Permissible Concentration of Radionuclides in Air and Water for Occupational Exposure."</p> <p>Briefly describe use of handbook.</p> <p>Inform students MPD will be discussed further in later lesson.</p> <p>Slide 6.2.1.53.--Summary</p> <p>Review problem set and assign to students. Inform students when problems should be completed.</p>

Practice Exercises

Principles of Ionizing Radiation

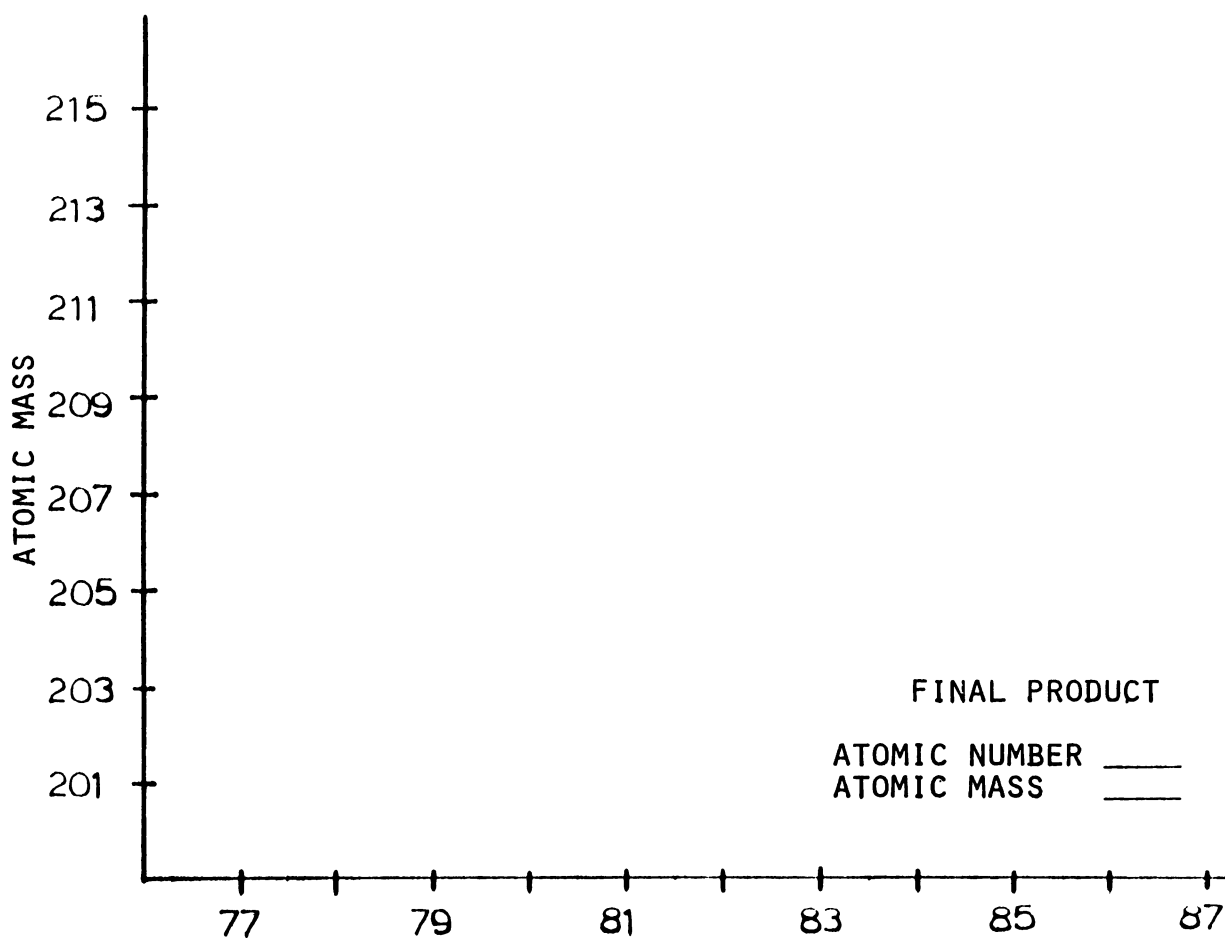
Module 6

Unit 2

Lesson 1

1. On the graph provided, chart the radioactive decay of radioisotope $^{215}_{85}\text{Q}$ if the following types of radiation are emitted in the sequence provided. What is the atomic number and mass of the element at the end of the emissions?

1. Alpha particle
2. Negatron
3. Gamma radiation and alpha particle
4. Positron
5. Alpha particle



Practice Exercises	
Principles of Ionizing Radiation	Module 6 Unit 2 Lesson 1
<p>2. Given that a quantity of Uranium-238 is decaying at the rate of 2.6×10^5 disintegrations per second, what amount of Uranium (in curies) would emit this activity?</p> <p>3. How many disintegrations per second would be expected from a Strontium-90 with an activity of 500 curies?</p> <p>4. A beta emitter has a monitor reading of 150 mrad/hr at 0.5 cm. Calculate the dose equivalent. How many hours per week could an employee be exposed and not exceed the MPD for hand exposure over 13 weeks?</p>	

Practice Exercises	
Principles of Ionizing Radiation	Module 6 Unit 2 Lesson 1
<p>5. Assume that a radioactive source is emitting beta and gamma radiation and that monitoring equipment has indicated an absorbed and exposure rate of 2.5 mrad/hr and 12.0 mR/hr, respectively. How many hours per week could the employee remain working in this environment and not exceed the MPD value for whole body exposure over a period of 13 weeks?</p>	

Practice Exercises--Solutions

Principles of Ionizing Radiation

Module 6

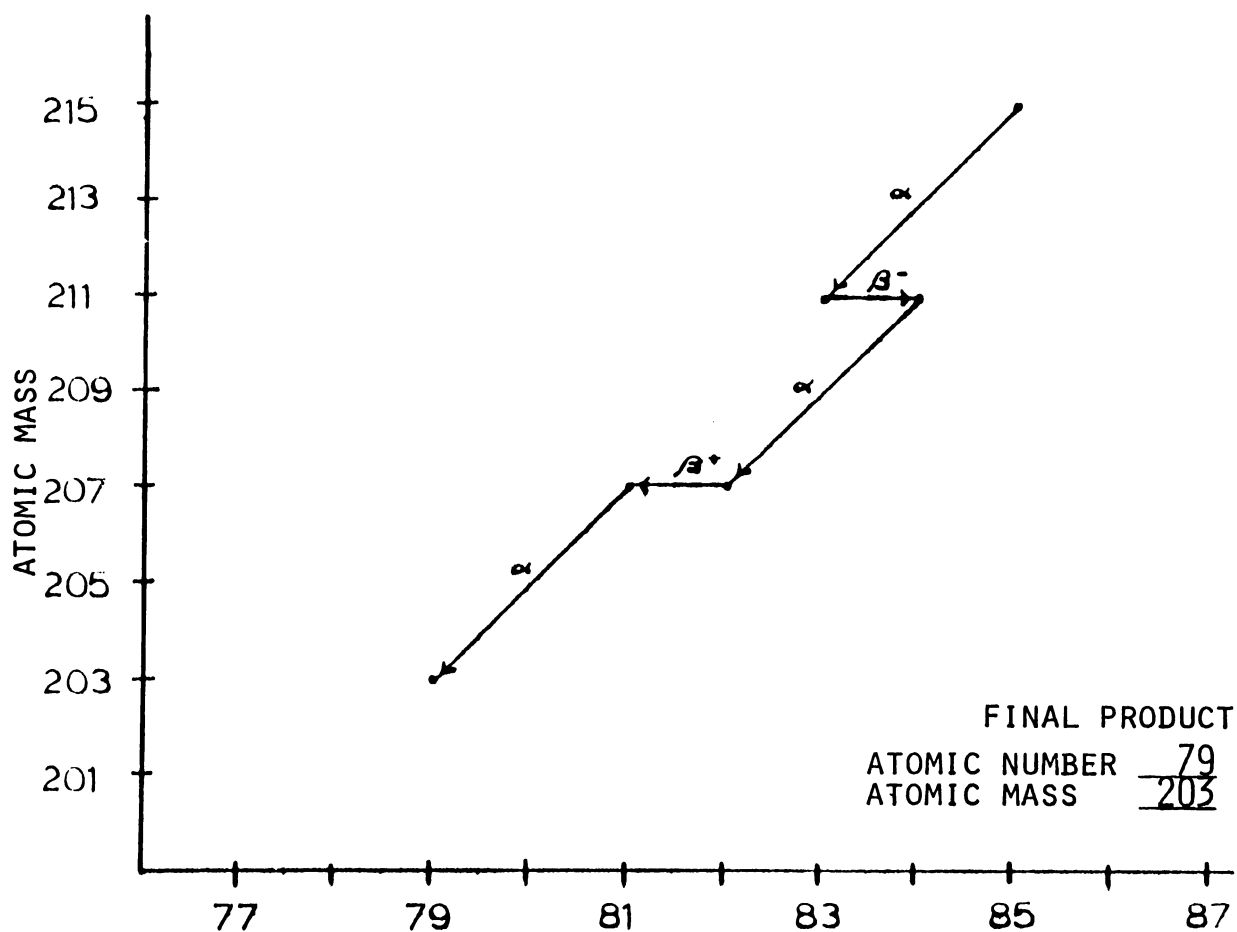
Unit 2

Lesson 1

1. On the graph provided, chart the radioactive decay of radioisotope $^{215}_{85}\text{Q}$ if the following types of radiation are emitted in the sequence provided. What is the atomic number and mass of the element at the end of the emissions?

1. Alpha particle
2. Negatron
3. Gamma radiation and alpha particle
4. Positron
5. Alpha particle

Solution:



Practice Exercises--Solutions

Principles of Ionizing Radiation

Module 6

Unit 2

Lesson 1

2. Given that a quantity of Uranium-238 is decaying at the rate of 2.6×10^5 disintegrations per second, what amount of Uranium (in curies) would emit this activity?

Solution:

$$\frac{2.6 \times 10^5 \text{ disintegrations}}{\text{second}} \times \frac{\text{sec-curie}}{3.7 \times 10^{10} \text{ disintegrations}} = 7.027 \times 10^{-6} \text{ Ci}$$

3. How many disintegrations per second would be expected from a Strontium-90 with an activity of 500 curies?

Solution

$$500 \text{ Ci} \times \frac{3.7 \times 10^{10} \text{ dis}}{\text{sec-Ci}} = 1.85 \times 10^{13} \text{ disintegrations/second}$$

4. A beta emitter has a monitor reading of 150 mrad/hr at 0.5 cm. Calculate the dose equivalent. How many hours per week could an employee be exposed and not exceed the MPD for hand exposure over 13 weeks?

Solution

$$\begin{aligned} \text{rem} &= \text{rad} \times \text{QF} \\ &= \frac{150 \text{ mrad}}{\text{hr}} \times 1 \\ &= \frac{150 \text{ mrem}}{\text{hr}} \end{aligned}$$

$$\text{MPD}_{\text{hand}} = 25 \text{ mrem/qrtr}$$

$$\frac{25 \text{ mrem/13 wks}}{150 \times 10^{-3} \text{ mrem/hr}} = 166.7 \text{ hours/13 weeks}$$

$$\frac{166.7 \text{ hours}}{13 \text{ weeks}} = 12.8 \text{ hours/week}$$

Practice Exercises--Solutions

Principles of Ionizing Radiation

Module 6
Unit 2
Lesson 1

5. Assume that a radioactive source is emitting beta and gamma radiation and that monitoring equipment has indicated an absorbed and exposure rate of 2.5 mrad/hr and 12.0 mR/hr, respectively. How many hours per week could the employee remain working in this environment and not exceed the MPD value for whole body exposure over a period of 13 weeks?

Solution

$$QF_{(\text{gamma})} = 1$$

$$QF_{(\text{beta})} = 1$$

$$\therefore 12 \text{ mR/hr} \cdot 1 = 12.0 \text{ mrem/hr}$$

$$2.5 \text{ mR/hr} \cdot 1 = \frac{2.5 \text{ mrem/hr}}{14.5 \text{ mrem/hr}} - \text{Total dose equivalent/hr}$$

For 13-week period

$$\text{MPD} = 3.0 \text{ for whole body exposure}$$

$$\therefore \text{Total hours} = \frac{3.0 \text{ rem/13 weeks}}{14.5 \times 10^{-3} \text{ rems/hr}} = 206.9 \text{ hrs/13 weeks}$$

$$\frac{206.9 \text{ hrs}}{13 \text{ weeks}} = 15.9 \text{ hours/week}$$

Lesson Outline	
Monitoring Instrumentation	Module 6 Unit 2 Lesson 2
TOPIC	REMARKS
<p>I. Instrumentation--Introduction</p> <p>A. Radiation detection instruments operate on monitoring the effect of ionization; e.g., ions produced in a given volume of gas can be measured.</p> <p>B. No single instrument performs acceptably under all conditions and requirements.</p> <p>C. Radiation detectors most widely used include:</p> <ol style="list-style-type: none"> 1. Ionization chamber. 2. Proportional chamber. 3. Geiger-Mueller counter. 4. Scintillation detector. 5. Photographic devices. 6. Solid state and activation devices. <p>D. Prominent personnel monitoring devices include:</p> <ol style="list-style-type: none"> 1. Film badges. 2. Pocket dosimeters. 3. Pocket ion chambers. <p>E. Protection Measurements</p> <ol style="list-style-type: none"> 1. Response of a detector due only to energy absorbed by detector itself. 2. Proper choice of detector can provide readings proportional to actual absorbed dose. 3. Generally, response of instrument is not <u>exactly</u> equivalent to the response of human tissue receiving the same energy--caused by secondary ionization factors. 4. However, may be assumed to be equal. 	

Lesson Outline	
Monitoring Instrumentation	Module 6 Unit 2 Lesson 2
TOPIC	REMARKS
<p>F. Accuracy</p> <ol style="list-style-type: none"> 1. Absorbed dose can rarely be determined directly; estimations must be acceptable. 2. MPD values conservative; can tolerate an accuracy of $\pm 15\%$. 3. Accuracy of X- and gamma readings usually better than neutrons and particulate radiation. 4. Major efforts to increase accuracy should only be of concern if readings approximate MPD; e.g., care afforded exposed individual dependent upon dose received. <p>II. Instrumentation</p> <p>A. Ionization Chamber Instruments</p> <ol style="list-style-type: none"> 1. Principle <ol style="list-style-type: none"> a. ionizing radiation falls on chamber b. ions are formed in chamber from radiation c. primary ions are collected at the cathode and anode d. potential voltage difference is measured e. potential difference is proportional to quantity of ionizing radiation 2. Uses. <ol style="list-style-type: none"> a. measures relatively high level of radiation b. can measure both particulate and electromagnetic radiation c. responds to any ionization produced--difficult to discriminate between radiation types and specifically between particles of different LET 	<p>Slide 6.2.2.1.--Ionization Chamber</p> <p>Demonstrate the ionization chamber instrument to the students. Be sure to discuss:</p> <ol style="list-style-type: none"> A. Components of the instrument. B. Primary use. C. Range and type of radiation which can be measured. D. Meter readings; range, units. E. Adaptation required for different types of radiation. F. Steps for use.

Lesson Outline		
Monitoring Instrumentation		Module 6 Unit 2 Lesson 2
TOPIC		REMARKS
<p>3. Ionization chamber.</p> <ul style="list-style-type: none"> a. usually 190-320 cm³ in volume b. the larger the chamber, the greater the sensitivity and required operational voltage c. can be modified to measure all types of radiation d. usually open to atmosphere and requires corrections for ambient temperature and pressure e. sealed chambers may change because of leakage or absorption and adsorption on inside surface f. wall of chamber of critical importance--affects reading; thickness must approximate maximum range of ionized particles produced g. chamber can be <ul style="list-style-type: none"> (1) air equivalent--measures exposure (2) tissue equivalent--simulates human tissue and is calibrated to measure absorbed dose. <p>4. Advantages.</p> <ul style="list-style-type: none"> a. simple, rugged device b. reliably determines absorbed dose or exposure <p>5. Disadvantages.</p> <ul style="list-style-type: none"> a. special design required to discriminate <u>well</u> between types of radiation b. must have general knowledge of radiation spectrum of interest 		<p>Slide 6.2.2.2.--Ionization Chamber Wall Thickness</p> <p>Present information about wall thickness only to emphasize criticality of wall thickness.</p> <p>Briefly describe the two types of chambers and advantages of each.</p>

Lesson Outline	
Monitoring Instrumentation	Module 6 Unit 2 Lesson 2
TOPIC	REMARKS
<p>B. Proportional Counter Instruments</p> <p>1. Principle</p> <ul style="list-style-type: none"> a. same as ionization chamber b. voltage increased such that secondary ionization occurs c. secondary ions contribute to ion current pulse (gas amplification) d. amplification ($10^3 - 10^4$) increases sensitivity e. proportionality between counter current and energy fluence rate of radiation maintained <p>2. Uses.</p> <ul style="list-style-type: none"> a. more useful in measuring particle radiation than photon radiation b. can measure alpha and beta and discriminate between the two types c. if chamber lined with boron film, thermal neutrons can be measured d. fast neutrons of low energy can also be measured e. spectrometry of low energy photon and alpha particle possible <p>3. Proportional counter chamber.</p> <ul style="list-style-type: none"> a. choice of gas and wall construction dependent on purpose and type of measurement b. can be air or tissue equivalent c. by changing thickness of wall, one can get an indication of absorbed dose at various levels in human tissue 	<p>Slide 6.2.2.3.--Proportional Counter</p> <p>Demonstrate the proportional counter instrument to the students. Be sure to discuss:</p> <ul style="list-style-type: none"> A. Components of the instrument. B. Primary use. C. Range and type of radiation which can be monitored. D. Meter readings; range, units. E. Adaptation required for different types of radiation. F. Steps for use.

Lesson Outline	
Monitoring Instrumentation	Module 6 Unit 2 Lesson 2
TOPIC	REMARKS
<p>4. Advantages.</p> <p>a. discrimination</p> <p>(1) gamma when counting neutrons</p> <p>(2) beta when counting alpha</p> <p>b. high sensitivity</p> <p>c. relative high accuracy and counting efficiency</p> <p>5. Disadvantages.</p> <p>a. insulation requirements around components</p> <p>b. inaccuracies due to losses of absorbed energy; may decrease accuracy by 50%</p> <p>C. Geiger-Mueller (G-M) Counter</p> <p>1. Used extensively as sensitive radiation detector.</p> <p>2. Principle.</p> <p>a. similar to ionization chamber</p> <p>b. applied voltage increased such that secondary ionization occurs to all gas atoms in chamber</p> <p>c. because of secondary ionization</p> <p>(1) greatly increased sensitivity</p> <p>(2) response not generally related to type of ionizing event</p> <p>3. Electrical pulse generated internally independent of type of ionizing event--response of detector cannot be related directly to either absorbed dose or exposure.</p>	<p>Slide 6.2.2.4.--G-M Counter</p> <p>Demonstrate the G-M counter to the students. Be sure to discuss:</p> <p>A. Components.</p> <p>B. Primary use.</p> <p>C. Range and types of radiation which can be detected.</p> <p>D. Meter readings; range, units.</p> <p>E. Adaptations required for different types of radiation.</p> <p>F. Steps for use.</p>

Lesson Outline	
Monitoring Instrumentation	Module 6 Unit 2 Lesson 2
TOPIC	REMARKS
<p>4. Uses.</p> <ul style="list-style-type: none"> a. used to detect existence of low level radiation; e.g., 0-20 mR/hr b. under special conditions, can yield response proportional to exposure over limited ranges of photon energy c. primarily used to detect low energy beta and gamma radiation <ul style="list-style-type: none"> (1) separated if beta absorbing window used (2) three counts needed <ul style="list-style-type: none"> C₁--background C₂--windowless (gamma and beta) C₃--with window (gamma only) (3) calculate <ul style="list-style-type: none"> $\text{gamma} = C_3 - C_1$ $\text{beta} = C_2 - C_3 - C_1$ d. can measure gamma in the presence of neutrons <p>5. Characteristics.</p> <ul style="list-style-type: none"> a. made in variety of shapes, sizes, and compositions--must be matched to use b. in general, sensitivity to beta dependent upon angle of incidence of radiation; i.e., G-M counter directional c. dead time--time required to initiate avalanche and for quenching to occur--may affect counter response 	<p>Briefly describe the role of "quenching gas."</p>

Lesson Outline	
Monitoring Instrumentation	Module 6 Unit 2 Lesson 2
TOPIC	REMARKS
<p>d. G-M counter should not be used if count rate > 1000 cpm</p> <p>(1) G-M counter energy dependent</p> <p>(2) increased radiation a decrease or blockage of meter reading</p> <p>(3) G-M counter may show "no field" when in fact field may be very high.</p> <p>e. G-M counters should not be used for measurement of short, high intensity pulses; may cause meter blockage</p> <p>6. Advantages.</p> <p>a. sensitivity</p> <p>b. generally stable and rugged</p> <p>c. portable</p> <p>7. Disadvantages.</p> <p>a. readings cannot be directly related to absorbed dose or exposure</p> <p>b. meter may block and read "no field" in high radiation field</p> <p>c. directional sensitivity for beta radiation</p> <p>D. Scintillation Detector</p> <p>1. Depends on light produced when ionizing radiation interacts with a phosphor or crystal capable of producing light.</p> <p>2. Components.</p> <p>a. scintillator--photo-sensitive crystal</p>	<p>Ask the students how they could tell whether a G-M counter was inoperative or blocked.</p> <p><u>Answer</u>--background radiation should cause at least <u>one</u> count every few seconds. If <u>no</u> counts are registered, the counter is either inoperative or blocked.</p> <p>Slide 6.2.2.5.--Scintillation Detector</p> <p>Demonstrate the scintillation detector instrument to the students. Be sure to discuss:</p> <p>A. Components of the instrument.</p> <p>B. Primary use.</p> <p>C. Range of radiation which can be monitored.</p> <p>D. Meter readings; range, units.</p>

Lesson Outline	
Monitoring Instrumentation	Module 6 Unit 2 Lesson 2
TOPIC	REMARKS
<ul style="list-style-type: none"> b. photomultiplier c. electronic counting equipment <p>3. Principle.</p> <ul style="list-style-type: none"> a. ionizing radiation falls on scintillation counter b. crystal is excited and emits light c. light produced registers on photomultiplier and converted to electrical impulses d. electrical impulses magnified and registered on microammeter e. number and size of pulses related to energy deposited in the scintillator <p>4. Uses.</p> <ul style="list-style-type: none"> a. measures gamma radiation in presence of beta--NaI crystals b. measures beta in the presence of high energy gamma--thin plastic scintillators c. soft X-rays d. alpha particles--CsI:TL crystal--radioactive sample can be placed in scintillation chamber e. most useful--alpha and low-level gamma radiation <p>5. Advantages.</p> <ul style="list-style-type: none"> a. very sensitive instrument b. monitor low energy source 5 mR/hr above background c. can be used as spectrometer; a mixture of several radionuclides can be quantitatively and qualitatively analyzed 	<p>Be sure to discuss--continued.</p> <p>E. Adaptation required for different types of radiation; e.g., phosphors.</p> <p>F. Technique for using instrument; i.e., steps for use.</p>

Lesson Outline	
Monitoring Instrumentation	Module 6 Unit 1 Lesson 2
TOPIC	REMARKS
<ul style="list-style-type: none"> d. discrimination between different types and energies of radiation can be made by pulse shape or height analysis e. relatively high counting efficiency; e.g., alpha and beta approach 100% <p>6. Disadvantages.</p> <ul style="list-style-type: none"> a. photomultiplier and crystals relatively fragile b. scintillator photomultiplier and guides must be kept in light-tight case c. some crystals used are easily damaged by moisture and humidity <p>E. Photographic Devices</p> <ul style="list-style-type: none"> 1. Designed to provide a reasonably accurate, permanent record of cumulative exposure. 2. Principle. <ul style="list-style-type: none"> a. radiation interacts with silver halide in photographic emulsion b. silver ions attracted to negatively charged sensitivity center on crystal c. silver ions reduced to free silver d. during processing, silver ions are removed; free silver stays e. quantity of silver is proportional to ionizing radiation 3. Range of film, dependent upon: <ul style="list-style-type: none"> a. characteristics of emulsion b. filtration used c. processing techniques d. type and quality of exposing radiation 	<p>Slide 6.2.2.6.--Film Badge</p> <p>Show students a film badge. Describe its</p> <ul style="list-style-type: none"> A. Components B. Primary use

Lesson Outline	
Monitoring Instrumentation	Module 6 Unit 2 Lesson 2
TOPIC	REMARKS
<p>4. Range usually $10^3:1$.</p> <p>5. Uses.</p> <ul style="list-style-type: none"> a. personnel monitors b. generally used to monitor beta, neutron, and gamma radiation c. only beta of energy greater than 0.2 MeV can penetrate film casement <p>6. Properties.</p> <ul style="list-style-type: none"> a. usually quite small b. require no power supplies c. special holders and packs devised for various parts of the body; e.g., wrists and fingers <p>7. Processing.</p> <ul style="list-style-type: none"> a. relatively expensive; not generally cost effective for less than 200 people b. change badges every 2 to 4 weeks but can be changed quarterly or weekly c. calibration films must be included in each process because of emulsion differences <p>8. Advantages.</p> <ul style="list-style-type: none"> a. permanent record b. size and stability c. can discriminate between types of radiation d. can be used on large populations <p>9. Disadvantages</p> <ul style="list-style-type: none"> a. dependent upon direction of incident radiation 	<p>Ask students for a potential problem in changing badges quarterly.</p> <p><u>Answer</u>--Accidental exposure may go undetected for a long period of time.</p>

Lesson Outline	
Monitoring Instrumentation	Module 6 Unit 2 Lesson 2
TOPIC	REMARKS
<ul style="list-style-type: none"> b. cannot assess absorbed dose and dose equivalent to within $\pm 20\%$-50% for simple radiation fields c. calibration and processing somewhat complex d. film emulsion reactive to water vapor <p>F. Solid State and Activation Devices</p> <ul style="list-style-type: none"> 1. Any solid material which, when irradiated, exhibits a property whose response is a function of the energy absorbed may, in principle, be used as a radiation measuring device. 2. Physical properties discussed include: coloration, photoluminescence, thermoluminescence, photoconduction. 3. Thermoluminescent detectors. <ul style="list-style-type: none"> a. useful in measuring X- and gamma radiation and high energy beta particles b. principle <ul style="list-style-type: none"> (1) material exposed to radiation is ionized and "holes" develop in lattice structure (2) material then heated to provide recombination energy (3) as recombination occurs, light emitted (4) quantity of light emitted proportional to ionizing radiation exposure c. typical materials include <ul style="list-style-type: none"> (1) calcium fluoride (2) lithium fluoride (3) calcium sulfate 	<p>Slide 6.2.2.7.--Thermoluminescent Detectors</p> <p>Briefly demonstrate photo- and thermoluminescent devices to students.</p>

Lesson Outline	
Monitoring Instrumentation	Module 6 Unit 2 Lesson 2
TOPIC	REMARKS
<ul style="list-style-type: none"> d. advantages <ul style="list-style-type: none"> (1) can be quite small (0.01 - 1 gram) (2) rugged and durable (3) wide range (10 mR - 10⁵R) (4) minimum error (±5% - 10%) (5) reusable e. disadvantages <ul style="list-style-type: none"> (1) device required to "read" detector-- device heats detector and then reads light emitted (2) <u>fading</u>--room temperature causes loss of signal CaSO₄--30% decrease after 8 hours; 65% decrease after 8 days 	
<ul style="list-style-type: none"> 4. Photoluminescent devices. <ul style="list-style-type: none"> a. similar use as thermoluminescent devices b. principles <ul style="list-style-type: none"> (1) same as thermoluminescent device (2) except light emitted when glass exposed to ultraviolet light c. advantages <ul style="list-style-type: none"> (1) range (10mR-10³R) dependent upon type of glass (2) portable and rugged (3) reusable in some instances d. disadvantages <ul style="list-style-type: none"> (1) device required to "read" detector (2) <u>fading</u> 	Slide 6.2.2.8.--Photoluminescent Devices

Lesson Outline	
Monitoring Instrumentation	Module 6 Unit 2 Lesson 2
TOPIC	REMARKS
<p>5. Semiconductor device.</p> <ul style="list-style-type: none"> a. exposure to radiation causes change to conductivity of material b. acts as solid ionization chamber c. used to measure alpha, beta, X-, and gamma radiation d. range: 10^{-6} - 10^{-4} R/hr e. problem: somewhat temperature dependent <p>6. Chemical reaction detector.</p> <ul style="list-style-type: none"> a. ionization radiation may cause chemical reaction b. e.g., Frick dosimeter (FeSO_4) <p>G. Personnel Monitoring Devices</p> <p>1. Film badges.</p> <ul style="list-style-type: none"> a. designed to provide a reasonably accurate, permanent record b. can monitor whole body or parts of the body c. problem--film must be processed to determine exposure d. discussed previously (Section E) <p>2. Pocket dosimeter.</p> <ul style="list-style-type: none"> a. indicates accumulated exposure to radiation at any time b. can be read by the individual c. does not provide a permanent record of exposure 	<p>Briefly explain operation of chemical reaction detector.</p> <p>Because of the importance of personnel monitoring, this section reviews the major types of detection devices used for personnel monitoring.</p> <p>Slide 6.2.2.9.--Personnel Monitoring Devices</p> <p>Demonstrate pocket dosimeter to students.</p>

Lesson Outline	
Monitoring Instrumentation	Module 6 Unit 2 Lesson 2
TOPIC	REMARKS
<ul style="list-style-type: none"> d. principle <ul style="list-style-type: none"> (1) primarily an ion chamber (2) must be recharged to return register to zero e. can be worn similar to film badge f. usually prepared with radiation scale to 200 mR 	
<ul style="list-style-type: none"> 3. Pocket chamber. <ul style="list-style-type: none"> a. similar in size and shape to a fountain pen b. indicates cumulative exposure c. principle similar to an ion chamber--change in charge d. is measured on a scale calibrated in mR. e. requires separate unit to read device f. as with pocket dosimeter, unit must be periodically recharged 	Demonstrate pocket chamber.
III. Choice and Use of Instruments <ul style="list-style-type: none"> A. Factors affecting the selection of instruments include: <ul style="list-style-type: none"> 1. Direction dependence of instrument. 2. Response rate. 3. Susceptibility to environment interference. 4. Precision and accuracy of calibration. 5. Specific use. B. Generally accepted use. 	Slide 6.2.2.10.--Summary Briefly review the primary use for each instrument discussed: <ul style="list-style-type: none"> A. Ionization chamber B. Proportional counter C. G-M counter D. Scintillation detector E. Photographic devices F. Solid state and activation devices G. Film badges H. Pocket dosimeters I. Pocket ion chambers

Lesson Outline	
Control of Ionizing Radiation	Module 6 Unit 2 Lesson 3
TOPIC	REMARKS
<p>I. Identify Radiation Safety Problems</p> <p>A. Radiation cannot be seen, felt, heard, tasted, or smelled.</p> <p>B. Can be identified and measured by instruments; can be adequately controlled.</p> <p>C. Radiation exposure can be controlled:</p> <ol style="list-style-type: none"> 1. Erection of barriers and warning signs. 2. Safe operational practices. 3. Operational procedures which minimize exposure times. <p>D. Consideration for Safe Control</p> <ol style="list-style-type: none"> 1. Type of work. <ol style="list-style-type: none"> a. processing feed materials for nuclear reactors. b. application of radioactive materials--luminous instrument dials c. radiation fields occurring with X-ray machine d. thickness gauges e. static eliminators f. radioactive tracers 2. Sources of radiation. <ol style="list-style-type: none"> a. amount and type of radiation important b. varying radioactivity of radioisotope per unit activity c. sealed sources <ol style="list-style-type: none"> (1) vary in size (2) problems arise in potential leaks 	<p>Ask students which factors must be evaluated when considering safe control of radiation.</p> <p>Slide 6.2.3.1.--Consideration for Safe Control</p> <p>Review from Unit 2, Lesson 1.</p> <p>Slide 6.2.3.2.--Consideration for Safe Control</p> <p>Slide 6.2.3.3.--Radioactivity of Radioisotope</p>

Lesson Outline	
Control of Ionizing Radiation	Module 6 Unit 2 Lesson 3
TOPIC	REMARKS
<ul style="list-style-type: none"> d. radioisotopes (unsealed sources) <ul style="list-style-type: none"> (1) hazard varies by isotope (1) 1 to 2 Ci--high level hazard (3) radiation sources of 0.5 mCi should be shielded if gamma and neutron radiation involved e. radioactive metals <ul style="list-style-type: none"> (1) vary greatly in degree of hazard (2) may be held in hand if gloves worn (3) major problem--spread of loose material (e.g., flaking, grinding chips) (4) control--e.g., glove box 3. Operational factors. <ul style="list-style-type: none"> a. required level of radiation protection and potential problems which might arise can be determined--factors include: b. area involved (sq. ft.), number of rooms, buildings c. number of employees potentially exposed to radiation and location d. chemical and physical states of radioactive material and its use e. incidents likely to occur f. nonradiation hazards involved; e.g., high voltage 	<p>Slide 6.2.3.4.--Consideration for Safe Control</p>

Lesson Outline	
Control of Ionizing Radiation	Module 6 Unit 2 Lesson 3
TOPIC	REMARKS
<p>5. Second factor with respect to time is half-life. If exposure potential high, may wish to wait for radioactive decay to occur.</p> <p>a. loss of strength can be calculated if original activity and date of measure are known.</p> <p>b. decrease of activity of source is equal to $(1/2)^n$ where n = number of half-lives which have passed since last known measurement.</p> <p><u>Example</u></p> <p>An isotope acquired from a national laboratory in June 1977 a surplus Co-60 source which had an exposure rate of 40 mR/hr at 10 cm in January of 1970.</p> <p>What is the exposure rate the user could expect in June 1977?</p> <p><u>Solution</u></p> <p>June 1977 to January 1970 = 7.5 years</p> <p>Half-life of Co-60 = 5.3 years</p> <p>Half-life = $\frac{7.5}{5.3} = 1.415$</p> <p>Using $(1/2)^n$</p> <p>$1.415 \text{ half-lives} = (1/2)^{1.415} = 0.375$</p> <p>Exposure rate (June 1977) =</p> <p>$40 \text{ mR/hr} \cdot 0.375 = 15 \text{ mR/hr}$</p> <p>D. Distance</p> <p>1. Second tool of protection.</p> <p>2. Radiation source is reduced by a factor of 1 divided by the square of the distance between the worker and the source--"inverse square law."</p>	<p>Concept of half-life previously discussed.</p> <p>Slide 6.2.3.8.--Example--Calculation of Half-Life Effect</p> <p>Slide 6.2.3.9.--Solution--Calculation of Half-Life Effect</p> <p>Note: Inform students that tables exist which calculate $(1/2)^n$ for values of n; such a table is found in the student's textbook.</p> <p>Slide 6.2.3.10.--Distance Versus Radiation Exposure</p>

Lesson Outline	
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<ul style="list-style-type: none"> d. shields may be cylindrical or box-shaped, depending on local needs e. local shields often built of laid bricks, concrete blocks; concern <ul style="list-style-type: none"> (1) cracks between blocks <ul style="list-style-type: none"> -stagger cracks -grooved bricks (2) scattering of beam--incident radiation f. highly radioactive sources may require remote control <ul style="list-style-type: none"> (1) require leaded glass (2) distance <p>F. Gamma Radiation Shielding</p> <ul style="list-style-type: none"> 1. Purpose--reduce exposure to acceptable level. 2. Gamma radiation--photon energy with high penetration capability. 3. Shielding must be high density. 4. Typical materials used include <ul style="list-style-type: none"> a. lead b. iron c. concrete 5. Amount of shielding required is discussed in terms of half-value layer (HVL). 6. HVL is the thickness of material required to decrease radiation by 0.5. 7. Typical materials and their HVL. 8. Possible to calculate shield effect in terms of HVL; i.e., attenuation of shield is equal to $(0.5)^n$ where n = the number of HVL of the shield. 	<p>Slide 6.2.3.13.--Shield Construction</p> <p>Slide 6.2.3.14.--Typical Remote Control System</p> <p>Shielding requirements will be examined by type of radiation.</p> <p>Slide 6.2.3.15.--Typical HVL Values</p>

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<p>9. Absorption of gamma radiation by shield is an exponential function; related by equation</p> $I = I_0 e^{-ux}$ <p>where</p> <p>I = exposure rate after passing through shield</p> <p>I₀ = initial exposure rate at shield</p> <p>u = absorption coefficient (cm⁻¹)</p> <p>x = thickness of shield (cm)</p> <p>a. u--function of photon energy of radiation and shielding material</p> <p>b. sample table</p> <p><u>Example</u></p> <p>How many cm would be required to reduce the exposure from a Co-60 source from 10 mR/hr to 2.5 mR/hr at the same distance? (HVL Co-60 = 1.1 cm Pb)</p> <p><u>Solution</u></p> <p><u>HVL Method</u></p> $\text{Decrease} = \frac{2.5 \text{ R/hr}}{10.0 \text{ R/hr}} = 0.25$ $(0.5)^n = 0.25$ $n = \frac{\log 0.25}{\log 0.5} = 2 \text{ HVL}$ $2 \text{ HVL} \times \frac{1.24 \text{ cm}}{\text{HVL}} = 2.48 \text{ cm Pb}$	<p>Slide 6.2.3.16.--Mass Attenuation Coefficients</p> <p>Adsorption coefficient calculated by dividing mass attenuation coefficient by the density of the shielding material.</p> <p>Slide 6.2.3.17.--Example-- Calculation of HVL</p> <p>Slide 6.2.3.18.--Solution Calculation of HVL</p>

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<p><u>Example</u></p> <p>Calculate the exposure rate for the previous example allowing for the build-up factor.</p> <p><u>Solution</u></p> $I_o = 0.1 \text{ mR/hr}$ $x = 3 \text{ cm Pb}$ $\rho(\text{Pb}) = \frac{11.34 \text{ g}}{\text{cm}^3}$ $u = \frac{0.015 \text{ cm}^2}{\text{g}} \times \frac{11.34 \text{ g}}{\text{cm}^3} = 1.19 \text{ cm}^{-1}$ <p>Using table</p> <p>for $ux = 1.19 \times 3 = 3.57$</p> <p>Cs-173 (MeV) = 0.66 MeV</p> $B = 1.79$ $I = (1.79)(0.1)e^{-(1.19 \cdot 3)}$ $= 5.0 \times 10^{-3} \text{ mR/hr}$ <p>11. Finally, it may be of value to project potential exposure rate at a given distance. To do so, must know</p> <ol style="list-style-type: none"> relative energies of nuclides activity <p><u>Formula</u></p> $\text{mR/hr} = \frac{5000 \text{ CE}f}{d^2}, \text{ where}$ <p>C = activity (mCi) E = energy (MeV) f = fraction of disintegration emitting E d = distance (cm)</p>	<p>Slide 6.2.3.24.--Solution--Calculation of Exposure Rate</p> <p>Slide 6.2.3.25.--Formula--Calculation of Gamma Exposure</p>

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<p>Note:</p> <ol style="list-style-type: none"> if d = ft, constant = 6 if more than one E is given off, each E · f must be calculated and a cumulative total of the exposure made. <p>12. Formula has two uses.</p> <ol style="list-style-type: none"> calculation of exposure rate of source being used in emergencies, you can calculate approximate safe distances. <p><u>Example</u></p> <p>A 50 mCi source of Co-60 is to be used in a new industrial process being used in your facility. What is the exposure rate of an unshielded source at 25 cm?</p> <p><u>Solution</u></p> $\text{mR/hr} = \frac{5000 \text{ CEf}}{d^2}$ <p>C = 50 mCi E = 2.5 MeV f = 1.0 d = 25 cm</p> $\text{mR/hr} = \frac{5000 \times 50 \times 2.5 \times 1.0}{(25)^2}$ $= 1000 \text{ mR/hr at 25 cm}$	<p>Slide 6.2.3.26.--Example--Calculation of Exposure Rate</p> <p>Slide 6.2.3.27.--Solution--Calculation of Exposure Rate</p> <p>Constants available in Table 7.5 in textbook.</p> <p>Note: Inform the students that an equivalent calculation can be made using the gamma ray constant (Γ).</p> $\text{mR/hr} = \frac{\Gamma A}{d^2} \quad \text{where}$ <p>A = amount (mCi) d = distance</p> <p>Same example.</p> $\Gamma(\text{Co-60}) = 13.0$ $A = 50 \text{ mCi}$ $d = 25 \text{ cm}$ $\text{mR/hr} = \frac{13.0 \cdot 50}{(25)^2}$ $= 1.04 \text{ R/hr}$ $= 1040 \text{ mR/hr}$

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<p><u>Solution</u></p> <p>a. Calculate tube output (T0) (from table)</p> <p>at 1 ft and 70 Kvp</p> $T0 = 4.0 \text{ R/100 mamp-sec}$ <p>at 12 ft</p> $T0 = \frac{4.0 \text{ R/100 mamp-sec}}{(12)^2}$ $= 0.028 \text{ R/100 mamp-sec}$ <p>b. Calculate W · U · T</p> $W = 200 \text{ mamp-min/wk}$ $U = 1$ $T = 0.25$ $W \cdot U \cdot T = \frac{200 \text{ mamp-min}}{\text{wk}} \times 1 \times 0.25$ $= \frac{50 \text{ mamp-min}}{\text{wk}}$ <p>c. Calculate attenuation</p> $\text{att} = \frac{0.1 \text{ R/week}}{\frac{0.028 \text{ R}}{100 \text{ ma-sec}} \times \frac{60 \text{ sec}}{\text{min}} \times \frac{50 \text{ ma-min}}{\text{wk}}}$ $= \frac{0.1 \text{ R/week}}{.84 \text{ R/week}} = 0.12$ <p>d. Calculate HVL needed</p> $(0.5)^n = 0.12$ $n = \frac{\log(0.12)}{\log(0.5)}$ $n = \frac{-0.9208}{-0.3010}$ $n = 3.06 \text{ HVL}$ <p>e. Using Table 5.8 (in textbook)</p> $3.06 \text{ HVL} \times \frac{0.15 \text{ mm Pb}}{\text{HVL}} = 0.459 \text{ mm Pb}$	<p>Slide 6.2.3.31.--Solution--</p> <p>Shielding Requirements--</p> <p>X-Ray</p>

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<p>9. Determination of shielding requirement for incident radiation also calculated in same manner.</p> <p>I. Beta Shielding</p> <ol style="list-style-type: none"> 1. Protection against beta radiation is less difficult because of short range of beta particles. 2. Range--thickness of material that no beta particles emitted from source can penetrate. 3. Range of the beta particles is a function of <ol style="list-style-type: none"> a. energy level of the beta particle b. absorbing material 4. Any shielding greater than range stops beta particles. 5. From literature, range in unit density material (cm) can be found. 6. Then, unit density divided by the density of the shielding material = the required shielding. <p><u>Example</u></p> <p>Calculate the minimum thickness of the wall of a glass test tube required to stop all beta particles from a P-32 source. (Glass = 2.3 gm/cm³)</p>	<p>Inform students that procedure is simplified in literature, but some information is required to work with tables:</p> <ol style="list-style-type: none"> 1. output 2. workload (W) 3. occupancy factor 4. directional factor (U) <p>Slide 6.2.3.32.--Properties of Commonly Used Beta Emitters</p> <p>Slide 6.2.3.33.--Example--Shielding Requirements--Beta</p>

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<u>Solution</u> From table Range in unit density P-32 = 0.8 cm Maximum range in glass $\frac{0.8 \text{ cm-gm}}{\text{cm}^3} \times \frac{\text{cm}^3}{2.3\text{gm}} = 0.35 \text{ cm glass}$ 7. Important consideration-- shielding materials must be light (small atomic weight); e.g., Al, H ₂ O, glass. <ul style="list-style-type: none"> a. beta converts to X-radiation which is more penetrating b. more likely with heavier compounds (Pb, iron) J. Alpha Particles <ul style="list-style-type: none"> 1. Alpha particles have limited range. 2. Alpha radiation cannot penetrate the layer of dead skin. 3. Danger--alpha emitter entering body--containment required; e.g., glove box, respirator. K. Neutron Shielding <ul style="list-style-type: none"> 1. Concepts of HVL and attenuation of coefficients described with gamma photons also apply to neutrons. 2. Most absorption materials for neutrons are high in hydrogen content (>20%). 3. Attenuation of hydrogen per energy level is prescribed in graph. 4. Attenuation for other medium. <ul style="list-style-type: none"> a. calculate hydrogen density in that medium b. multiply by attenuation coefficient 	Slide 6.2.3.34.--Solution-- Shielding Requirements-- Beta Slide 6.2.3.35.--Glove Box Slide 6.2.3.36.--Attenuation Coefficient of Hydrogen

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<p>5. Calculate HVL by</p> $\text{HVL} = 0.693 / \text{attenuation coefficient}$ <p><u>Example</u></p> <p>Calculate the attenuation due to hydrogen in a water shield 1.5 cm thick, 8 MeV neutrons.</p> <p><u>Solution</u></p> <p>Water is 11% H₂ by weight \therefore density (H₂) = 0.11 g/cm³</p> <p>From figure</p> <p>For MeV = 8.0, attenuation coefficient = 0.68 cm⁻¹/lgH₂/cm</p> <p>For water</p> $\text{attenuation coefficient} = 0.68 \times 0.11 = 0.075 \text{ cm}^{-1}$ $\text{HVL} = \frac{0.693}{0.075} = 9.24 \text{ cm}$ $\text{Number of HVL} = \frac{150}{9.24} = 16.2$ $\text{Attenuation} = (1/2)^n = (1/2)^{16.2} = 1.3 \times 10^{-5}$ <p>6. Can be used to calculate effect of shielding.</p> <p>7. Neutron activity usually leads to emission of gamma radiation; therefore, neutron shielding requires gamma shielding. Problem beyond the scope of this text.</p> <p>L. Summary--Shielding</p> <ol style="list-style-type: none"> 1. Discussed shielding for <ol style="list-style-type: none"> a. gamma b. X-ray c. beta d. alpha e. neutron 	<p>Slide 6.2.3.37.--Example-- Attenuation Neutron Shielding</p> <p>Slide 6.2.3.38.--Solution-- Attenuation Neutron Shielding</p>

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<ul style="list-style-type: none"> 2. Generally, all shielding serves some purpose; absorb radiation. 3. Design of shield depends upon attenuation and requirements. 4. Design of shield is more sophisticated than presented but general overview provided. <p>IV. Survey and Monitoring Procedures for Radiation Hazards</p> <p>A. Purpose</p> <ul style="list-style-type: none"> 1. Indicate general level of radiation in working environment. 2. Monitor changing levels of radiation. <p>B. Area Survey Includes</p> <ul style="list-style-type: none"> 1. Initial examination of facility. 2. Laboratory operating procedures. 3. Personnel habits. 4. Types of sources. 5. Methods used in handling sources. 6. Radiation levels. <p>C. Routine Surveys Should Be Scheduled</p> <ul style="list-style-type: none"> 1. To detect inadequate shielding; e.g., cracks. 2. Excessive surface and airborne contamination. 3. Improper disposal of waste. 4. Emphasis placed on unlikely and remote areas. <p>D. Routine measurements should be made at intervals during conduct of work for all steps and procedures, including</p> <ul style="list-style-type: none"> 1. Time of procedure and exposure 2. Distance from source. 	<p>Ask for questions.</p> <p>Slide 6.2.3.39.--Survey and Monitoring Procedures</p> <p>Give examples of how exposure level, distance from source, and time of exposure may vary for a given individual.</p>

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<ul style="list-style-type: none"> 3. Variations in exposure throughout procedure. 4. Specific areas of the body receiving more exposure. <p>E. Surface Contamination</p> <ul style="list-style-type: none"> 1. Evaluated by smear (wipe) test. 2. Determines amount of loose material may become airborne or transferred to personnel. 3. Specific surface area (100 cm²) wiped off with clean cloth, paper, or tape. 4. Smear samples removed to low background area and reading taken. 5. If area size (100 cm²) kept constant and equipment properly calibrated, readings can be quantified. 6. Corrective action taken as necessary. <p>F. Air Monitoring</p> <ul style="list-style-type: none"> 1. Sample may be collected by standard procedure using filters, electrostatic precipitators, and impingers. 2. Care must be taken to insure appropriate particles of all sizes are collected. 3. Sample of 10 m³ is usually adequate; grab sample may be performed if necessary. 4. Direct counting from surfaces where sample collected appropriate. 5. When counting alpha particles, correction factors must be determined for absorption of alpha by sample collecting filter. 	<p>Slide 6.2.3.40.--Surface Contamination</p> <p>Slide 6.2.3.41.--Air Monitoring</p>

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<ol style="list-style-type: none"> 6. In some instances, naturally occurring radon and thoron may interfere with readings; when counting alpha, adjustment must be made. 7. Values calculated to $\mu\text{Ci/cc}$ and compared with MPC for unrestricted areas. 8. If concentration known, quantity of nuclide taken in by personnel can be calculated by determining exposure time and determining the product of the exposure time, concentration, and 10^7 cc/8 hrs. 9. If nuclide source not known, arbitrary limit. <ol style="list-style-type: none"> a. 10^{-9} $\mu\text{C/cc}$--beta b. 10^{-12} $\mu\text{C/cc}$--alpha 10. In any instance where air contamination is possible, respirators should be used until radiation level determined. <p>G. Water Sample Analysis</p> <ol style="list-style-type: none"> 1. Sampled similar to air analysis. 2. Sample required--100-500 mL. 3. Sample evaporated and reading taken. 4. Results compared to MPC values. 5. If nuclide not known, qualitative tests can determine source. <p>H. Personnel Monitoring</p> <ol style="list-style-type: none"> 1. Most direct method of calculating personnel exposure. 2. Common equipment. <ol style="list-style-type: none"> a. film badge b. pocket chambers c. pocket dosimeter 	<p>Slide 6.2.3.42.--Water Sample Analysis</p> <p>Slide 6.2.3.43.--Personnel Monitoring</p> <p>Previously discussed.</p>

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<ul style="list-style-type: none"> 3. Personnel monitor should be matched to type and energy level of radiation. 4. Should be used when 25% of MPD for 13-week period may be exceeded. 5. More than one should be used at any given time to insure adequate. 6. Location of personnel monitor critical; should be unshielded (e.g., clothing) at a point of maximum exposure. 7. Records should be maintained concerning cumulative doses received. 	
I. Fixed Monitors	Slide 6.2.3.44.--Fixed Monitors
<ul style="list-style-type: none"> 1. Sometimes used to give <u>continuous recording</u> of dose rate at fixed location. 2. Visible or audible alarms warn of high radiation level. 3. e.g., <ul style="list-style-type: none"> a. doorway--if clothing contamination possible b. monitor hands and shoes on change of shift c. radiographic area 	
J. Control Design	
<ul style="list-style-type: none"> 1. Warning systems for high exposure levels. 2. Interlock systems which minimize exposure. 	
V. Facilities	Slide 6.2.3.45.--Facilities Design
A. Purpose--Provide adequate containment and allow for ease of cleanup.	

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<p>B. Design</p> <ol style="list-style-type: none"> 1. All surfaces should be smooth and nonporous; e.g., shelves, floors, sinks. <ol style="list-style-type: none"> a. unacceptable--uncoated wood, concrete, soapstone b. acceptable--tiles, polished stainless steel, plate glass c. ordinary paints, varnishes, and lacquers are not recommended. 2. Dust-collecting surfaces should be eliminated. <ol style="list-style-type: none"> a. lights recessed b. pipes enclosed c. shelves covered by doors d. cove corners between wall and floor facilitate cleanup e. ceilings enclosed to prevent contamination of roof trusses 3. Special piping and drainage systems should be plainly labeled if used for radioactive waste. 4. Design of room and shielding should prevent radiation leakage; e.g., <ol style="list-style-type: none"> a. construction of joints b. control for doors, pipes, conduits c. doorway maze 5. Special equipment often required. <ol style="list-style-type: none"> a. e.g., long-handled tools; tongs, forceps b. remote control devices, lead glass windows 	<p>Slide 6.2.3.46.--Room Construction</p> <p>Slide 6.2.3.47.--Maze</p> <p>Describe purpose of maze.</p> <p>Previously displayed. (Slide 6.2.3.14.)</p>

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<p>D. Posting the Area</p> <ol style="list-style-type: none"> 1. Areas of radioactivity should be posted if radioactivity present for longer than 8 hrs. 2. Sign should bear-- <ol style="list-style-type: none"> a. three-bladed radioactive caution symbol (magenta or purple on a yellow background) b. statement based upon level of radioactivity 3. Signs. <ol style="list-style-type: none"> a. CAUTION RADIATION AREA--potential dose of 5 mrem/hr or 100 mrem/week b. CAUTION RADIOACTIVE MATERIALS--for levels exceeding those described on slide <ol style="list-style-type: none"> (1) in room--sign (2) on container--label c. AIRBORNE RADIOACTIVITY AREA--if airborne contaminants may exceed MPC for 40 hours d. HIGH RADIATION AREA--if dose potential greater than 100 rem/hr 4. Post operating and handling instructions. <p>E. Trays and Handling Tools</p> <ol style="list-style-type: none"> 1. Work that may result in contamination of table top should be performed in box. 2. Tweezers and tongs should be used whenever possible to minimize exposure. 	<p>Slide 6.2.3.50.--Radioactive Warning Sign--Symbol</p> <p>Slide 6.2.3.51.--Radiation Warning Sign</p> <p>Slide 6.2.3.52.--Radiation Warning Sign</p> <p>Slide 6.2.3.53.--MPC Values for Radiation Warning Sign</p> <p>Slide 6.2.3.54.--Radiation Warning Sign</p> <p>Slide 6.2.3.55.--Radiation Warning Sign</p> <p>Slide 6.2.3.56.--Recommended Handling Procedures</p>

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<p><u>Solution</u></p> <p>From table</p> <p>MPC I-125 = 4.0×10^{-12} Ci/cc</p> <p>MPC P-32 = 5.0×10^{-10} Ci/cc</p> <p>Average daily water flow</p> $\frac{1.2 \times 10^7 \text{ ft}^3}{\text{yr}} \times \frac{\text{year}}{365 \text{ days}} \times \frac{2.8317 \times 10^4 \text{ cc}}{\text{ft}^3} = 9.31 \times 10^8 \text{ cc/day}$ <p>Daily Limits</p> <p>I-125</p> $\frac{4.0 \times 10^{-11} \text{ Ci}}{\text{cc}} \times \frac{9.31 \times 10^8 \text{ cc}}{\text{day}} = \frac{37.24 \text{ mCi}}{\text{day}}$ <p>P-32</p> $\frac{5.0 \times 10^{-10} \text{ Ci}}{\text{cc}} \times \frac{9.31 \times 10^8 \text{ cc}}{\text{day}} = \frac{0.466 \text{ Ci}}{\text{day}}$ <p>A maximum of 1 Ci per year for disposal of gross activity is set. Therefore, the number of daily disposals is limited.</p> <p>F. Solid Wastes</p> <ol style="list-style-type: none"> 1. Three methods for disposal. <ol style="list-style-type: none"> a. incineration b. burial c. commercial company 2. Incineration. <ol style="list-style-type: none"> a. good bulk-reducing method b. again, regulated by NRC c. rule of thumb--concentration released to unrestricted areas should not exceed limits specified for continuous exposure 	<p>Slide 6.2.3.62.--Solution--Water Contamination</p>

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<ul style="list-style-type: none"> d. when calculating release, concentration may be averaged over a maximum of one year e. ash left after incineration must also be treated as radioactive waste f. calculation of limits for released radioactivity identical to calculating release of air as previously described; must know <ul style="list-style-type: none"> (1) radionuclide(s) (2) airflow <p>3. Burial.</p> <ul style="list-style-type: none"> a. NRC rules fairly simple <ul style="list-style-type: none"> (1) allowed 12 burials per year (2) must be at <u>least</u> 6 ft apart and 4 ft deep (3) total quantity buried at any location may not exceed 1000 times figures on chart (Table 5.1 textbook) (4) if several nuclides buried, the sum of nuclide fractions cannot exceed one (1) b. state regulations may vary--be sure to check <p><u>Example</u></p> <p>A user of radionuclides plans to dispose of 2 mCi of Fe-59, 10 mCi of Cr-51, and 20 mCi of I-125 by burial.</p>	<p>Slide 6.2.3.63.--Example--Burial Procedure</p>

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<p>2. Degree of protection required is a function of</p> <ul style="list-style-type: none"> a. quantity and type of radioactivity b. nature of operation c. design of laboratory <p>3. Sealed containers do not usually require protective clothing.</p> <p>4. Garments.</p> <ul style="list-style-type: none"> a. in general, protective clothing not required if MPD for most critical organ (Handbook #69) not exceeded b. serves to prevent contamination outside laboratory facility c. low level work--requires <ul style="list-style-type: none"> (1) laboratory coats or coveralls (2) simple cloth or plastic bags on shoes (3) rubber or plastic gloves d. medium level work--requires <ul style="list-style-type: none"> (1) coveralls (2) caps (3) gloves (4) shoe covers e. high level work--requires <ul style="list-style-type: none"> (1) multi-layer of coveralls, shoes, etc.; clothes should be sealed (2) self-contained breathing apparatus should be used (3) should not be encountered during normal operation 	

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<p>F. Personnel Monitoring</p> <ol style="list-style-type: none"> 1. Discussed previously. 2. As review, any personnel who potentially may be in an area of 25% of MPD should carry personal monitoring device; e.g., film badge, dosimeter. <p>G. Medical Supervision</p> <ol style="list-style-type: none"> 1. Because of physical hazards, medical supervision essential. 2. Pre-employment examination. <ol style="list-style-type: none"> a. identify general physical condition b. quantity, if possible, of previous radiation exposures c. identify potential problems that may be magnified or potentially dangerous to employee in radioactive environment; e.g., <ol style="list-style-type: none"> (1) dermatological diseases (2) impairment of pulmonary ventilation (3) cataracts d. decision of employment and placement should consider these factors 3. Periodic medical examination. <ol style="list-style-type: none"> a. performed at appropriate intervals based upon <ol style="list-style-type: none"> (1) general health of employee (2) nature of work b. provide insight of any medical changes c. should not be used as reliable method for monitoring radiation hazard 	<p>Slide 6.2.3.68.--Medical Supervision</p>

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<ul style="list-style-type: none"> d. examination should include review of occupational hazard records and assessment of exposure doses e. medical advice should be followed with respect to continued radiation exposure <p>4. Follow-up examination.</p> <ul style="list-style-type: none"> a. desirable to have post-employment examination b. especially important if MPD exceeded c. provides <ul style="list-style-type: none"> (1) extended coverage for worker (2) adds to information on effects of radiation <p>5. Medical records.</p> <ul style="list-style-type: none"> a. should include medical and radiation exposure history b. job assignments and hazards involved should be recorded c. records of personal dose and accumulative exposure <p>VIII. Radiation Accidents</p> <p>A. Maximum effort should be made to minimize accidents; e.g.,</p> <ul style="list-style-type: none"> 1. Review operational procedures. 2. Check equipment. 3. For nonroutine or high-level operations, trial run should be performed. <ul style="list-style-type: none"> a. evaluate adequacy of procedure b. determine exposure time 	<p>Slide 6.2.3.69.--Radiation Accidents</p>

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Control of Ionizing Radiation	Module 6 Unit 2 Lesson 3
TOPIC	REMARKS
<p>4. Reports filed should include:</p> <ol style="list-style-type: none"> individuals exposed level of exposure nuclides involved concentration of nuclide released <p>IX. Responsibility of Industrial Hygienist</p> <p>A. In some instances, industrial hygienist has direct responsibility for radioactive sources. Responsibilities include:</p> <ol style="list-style-type: none"> 1. Comply with all government regulations. 2. Insure adequate supervision and training of personnel working with radioactivity. 3. Maintain inventory of radioactive sources being used, including type and amount. 4. Review operational procedures to evaluate potential <ol style="list-style-type: none"> personnel exposure accidents causing a release 5. Periodically survey radioactive areas for radiation levels. 6. Evaluate laboratory facility for proper design, construction, shielding, posting and labeling, etc. 7. Design alternative plans for containment and decontamination in the event of an accident. 8. Monitor disposal of wastes. 9. Supervise the monitoring system, including personnel monitoring procedures. 	<p>Slide 6.2.3.72.--Responsibilities of Industrial Hygienist</p>

Practice Exercises

Control of Ionizing Radiation

Module 6

Unit 2

Lesson 3

1. Because of an accident, the shielding around a 500 mCi Co-60 source has been destroyed. What is the minimum distance to the source a person can approach if a 2.5 mR/hr level is not exceeded?
2. Determine the thickness of concrete required to reduce the intensity of a Co-60 (gamma radiation) to 1/100 its value when unshielded. (Note: HVL Co-60 = 6.6 cm concrete.) Use HVL method.
3. Determine the thickness of lead (Pb) required to reduce the dose rate from a 30 mCi Cs-137 source to 5 mrem/hr at 30 cm from the source. Use formula $I = I_0 e^{-ux}$.
4. A technician in a pharmaceutical company routinely handles
 1. 500 mCi of I-131
 2. 100 mCi of Au-198
 3. 25 mCi of K-42all stored together in a hood. When he works in front of the hood, his mean body position is 60 cm from the active materials.
 - a. How long can the technician work in front of the hood per week without additional shielding?
 - b. What would be the effect on permissible working time if the technician used tongs, extending the mean body distance to 150 cm?

Practice Exercises

Control of Ionizing Radiation

Module 6
Unit 2
Lesson 3

5. An investigator is interested in releasing 200 mCi of Xe-133 through a hood. The air velocity into the hood is 150 ft/min through an opening 15 in high and 3 ft wide. Determine the permissible release rate so that the concentration in the effluent from the hood stack does not exceed maximum allowable concentrations averaged over a 24-hour period.
6. In a new process being introduced in your plant, an I-131 (gamma source) with an activity of 300 mCi will be used. In the process, the personnel will be a mean distance of 70 cm from the source and be exposed to the source for an average of 15 minutes per day. Because of the new process, it is possible that some of the material (I-131) may become airborne as particulate matter.

Calculate

- a. Potential exposure of unshielded source.
 - b. Lead shielding required to reduce exposure to below MPD level.
7. Prepare a list of activities which should be performed to evaluate and control the radiation hazard being introduced.

Practice Exercises--Solutions

Control of Ionizing Radiation

Module 6

Unit 2

Lesson 3

1. Because of an accident, the shielding around a 500 mCi Co-60 source has been destroyed. What is the minimum distance to the source a person can approach if a 2.5 mR/hr level is not exceeded?

Solution

First, calculate the exposure rate at 1 foot

$$\text{mR/hr} = \frac{6 \cdot C \cdot E \cdot f}{d^2}$$

$$\begin{aligned}\text{mR/hr} &= 6 \cdot C \cdot E \cdot f \text{ at 1 foot} \\ &= 6 \cdot 500 \cdot 2.50 \cdot 1 \\ &= \frac{7500 \text{ mR/hr}}{1 \text{ hr}}\end{aligned}$$

Find 2.5 mR/hr

$$\begin{aligned}ft^2 &= \frac{7500}{2.5} \\ ft &= \left(\frac{7500}{2.5} \right)^{\frac{1}{2}} \\ &= 54.7 \text{ ft} \approx \underline{55 \text{ feet}}\end{aligned}$$

People should not be closer than 55 feet.

2. Determine the thickness of concrete required to reduce the intensity of a Co-60 (gamma radiation) to 1/100 its value when unshielded. (Note: HVL Co-60 = 6.6 cm concrete.) Use HVL method.

Solution

Using attenuation table,

reduction by 0.01 requires 6.6 HVL

$$\therefore 6.6 \text{ HVL} \times \frac{6.6 \text{ cm}}{\text{HVL}} = 43.56 \text{ cm concrete}$$

3. Determine the thickness of lead (Pb) required to reduce the dose rate from 30 mCi Cs-137 to 5 mrem/hr at 30 cm from the source.

Solution

Unshielded

$$I_o \text{ mR/hr} = \frac{500CEf}{d^2}$$

$$\begin{aligned}C &= 30 \\ E &= 0.662 \\ f &= 0.85 \\ d &= 30\end{aligned}$$

(Solution Continued)

Practice Exercises--Solutions

Control of Ionizing Radiation

Module 6
Unit 2
Lesson 3

3. (Continued)

$$I_0 = 93.78 \text{ mrem/hr}$$

$$I = 5 \text{ mrem/hr}$$

$$x = \frac{-\ln(I/I_0)}{\mu}$$

Using table for mass attenuation coefficient, calculate μ .

$$\frac{0.132 \text{ cm}^2}{\text{g}} \times \frac{11.34 \text{ g}}{\text{cm}^3} = 1.50 \text{ cm}^{-1} \quad \text{Note: } \rho_{\text{Pb}} = \frac{11.34 \text{ g}}{\text{cm}^3}$$

Initially

$$x = \frac{-\ln(I/I_0)}{\mu}$$

$$= \frac{-\ln(5/93.78)}{1.50}$$

$$= 1.95 \text{ cm Pb}$$

Using tables, calculate build-up factors.

$$\mu = 2.925$$

$$\text{Pb} = 0.662 \text{ MeV}$$

$$\therefore B = 1.67$$

Finally,

$$I = BI_0 e^{-\mu x}$$

$$x = \frac{-\ln(I/BI_0)}{\mu}$$

$$x = \frac{-\ln(5/98.73 \cdot 1.95)}{1.50}$$

$$x = 2.4 \text{ cm Pb}$$

Practice Exercises--Solutions

Control of Ionizing Radiation

Module 6

Unit 2

Lesson 3

4. A technician in a pharmaceutical company routinely handles

1. 500 mCi of I-131
2. 100 mCi of Au-198
3. 25 mCi of K-42

all stored together in a hood. When he works in front of the hood, his mean body position is 60 cm from the active materials.

- a. How long can the technician work in front of the hood per week without additional shielding?
- b. What would be the effect on permissible working time if the technician used tongs, extending the mean body distance to 150 cm?

Solution

$$\begin{aligned}
 \text{a. mR/hr (I-131)} &= \frac{5000 \cdot 500 \cdot E \cdot f}{(60)^2} & .0116 E_1 &= 0.723 & f_1 &= 0.016 \\
 & & .0439 E_2 &= 0.637 & f_2 &= 0.069 \\
 &= 694.4 E \cdot f & .2985 E_3 &= 0.364 & f_3 &= 0.82 \\
 &= 694.4 \times 0.3725 & .0165 E_4 &= 0.284 & f_4 &= 0.058 \\
 &= 258.66 \text{ mR/hr} & .0020 E_5 &= 0.08 & f_5 &= 0.025 \\
 & & .3725 & & &
 \end{aligned}$$

$$\begin{aligned}
 \text{mR/hr (Au-198)} &= \frac{5000 \cdot 100 \cdot E \cdot f}{(60)^2} & .0022 E_1 &= 1.088 & f_1 &= 0.002 \\
 & & .0068 E_2 &= 0.676 & f_2 &= 0.01 \\
 &= 138.88 \cdot E \cdot f & .3914 E_3 &= 0.412 & f_3 &= 0.95 \\
 &= 138.88 \cdot 0.4004 & .4004 & & & \\
 &= 55.61 \text{ mR/hr} & & & &
 \end{aligned}$$

$$\begin{aligned}
 \text{mR/hr (K-42)} &= \frac{5000 \cdot 25 \cdot E \cdot f}{(60)^2} & .0006 E_1 &= 0.31 & f_1 &= 0.002 \\
 & & .2736 E_2 &= 1.52 & f_2 &= 0.18 \\
 & & .2742 & & & \\
 &= 34.72 \cdot E \cdot f & & & & \\
 &= 34.72 \cdot 0.2742 & & & & \\
 &= 9.520 \text{ mR/hr} & & & &
 \end{aligned}$$

Total Exposure

$$\begin{aligned}
 \text{I-131} &= 258.66 \text{ mR/hr} \\
 \text{Au-198} &= 55.60 \\
 \text{K-42} &= \underline{9.52} \\
 &= 323.78 \text{ mR/hr}
 \end{aligned}$$

(Solution Continued)

Practice Exercises--Solutions

Control of Ionizing Radiation

Module 6

Unit 2

Lesson 3

4. (Continued)

Total Body Exposure

3.0 rems/13 wk

$$\frac{3.0 \text{ rems}}{13 \text{ week}} = 0.231 \text{ rems/week}$$

Total hours/week

$$\frac{0.231 \text{ rems}}{\text{wk}} \times \frac{\text{hr}}{0.324 \text{ rems}} = 0.71 \text{ hrs/week, with no shielding, 60 cm--mean distance}$$

$$\text{b. mR/hr (I-131)} = \frac{5000 \cdot 500 \cdot 0.3725}{(150)^2} = 41.39 \text{ mR/hr}$$

$$\text{mR/hr (Au-198)} = \frac{5000 \cdot 100 \cdot 0.4004}{(150)^2} = 8.90 \text{ mR/hr}$$

$$\text{mR/hr (K-42)} = \frac{5000 \cdot 25 \cdot 0.2742}{(150)^2} = 1.52 \text{ mR/hr}$$

Total Exposure (150 cm)

I-131 = 41.39 mR/hr

Au-198 = 8.90

K-42 = $\frac{1.52}{51.81 \text{ mR/hr}}$

Total hours per week

$$\frac{0.231 \text{ rems}}{\text{week}} \times \frac{\text{hr}}{0.0518 \text{ rems}} = \frac{4.46 \text{ hrs}}{\text{week}}$$

An increase in distance by a factor of 2.5 is equivalent to a 625% decrease in exposure (inverse square law).

Lesson Outline

Control of Ionizing Radiation

Module 6

Unit 2

Lesson 3

5. An investigator is interested in releasing 200 mCi of Xe-133 through a hood. The air velocity in the hood is 50 ft/min, through an opening 15 in high and 3 ft wide. Determine the permissible release rate so that the concentration in the effluent from the hood stack does not exceed maximum allowable concentrations averaged over a 24-hour period.

Solution

$$\frac{\text{total flow of hood}}{24\text{-hr period}} = \frac{150 \text{ ft}}{\text{min}} \times 1.25 \text{ ft} \times 3 \text{ ft} \times \frac{1440 \text{ min}}{24 \text{ hr period}} \times \frac{2.83 \times 10^4 \text{ cc}}{\text{ft}^2}$$

$$\text{MAC (Xe-133)} = 0.3 \times 10^{-6} \text{ } \mu\text{Ci/cc (from table)}$$

$$\begin{aligned} \text{Maximum release for 24-hour} &= \frac{0.3 \times 10^{-6} \text{ } \mu\text{Ci}}{\text{cc}} \times \frac{2.292 \times 10^{10} \text{ cc}}{24 \text{ hour}} \\ &= 6876.0 \text{ } \mu\text{Ci/24 hours (permissible rate)} \\ &= 6.876 \times 10^{-3} \text{ Ci/24 hrs} \end{aligned}$$

Note: To release 0.2 Ci Xe would require

$$\frac{0.2 \text{ Ci}}{6.876 \times 10^{-3} \text{ Ci/24 hrs}} = \underline{29 \text{ days}}$$

Self-Test																																															
Nonionizing and Ionizing Radiation	Module 6																																														
<p>1. Define the following terms:</p> <p style="margin-left: 40px;">a. Photon _____</p> <p style="margin-left: 40px;">b. Wavelength _____</p> <p style="margin-left: 40px;">c. Frequency _____</p> <p>2. Rank the following regions of the electromagnetic spectrum from highest to lowest frequency and indicate whether they are a form of ionizing or nonionizing radiation.</p> <table style="width: 100%; border-collapse: collapse; margin-top: 10px;"> <thead> <tr> <th style="text-align: center; width: 10%;">Rank</th> <th style="text-align: center; width: 40%;">Region</th> <th style="text-align: center; width: 20%;">Ionizing</th> <th style="text-align: center; width: 30%;">Nonionizing</th> </tr> </thead> <tbody> <tr> <td style="text-align: center;">_____</td> <td>a. Ultraviolet</td> <td style="text-align: center;">_____</td> <td style="text-align: center;">_____</td> </tr> <tr> <td style="text-align: center;">_____</td> <td>b. Radio frequency</td> <td style="text-align: center;">_____</td> <td style="text-align: center;">_____</td> </tr> <tr> <td style="text-align: center;">_____</td> <td>c. Infrared</td> <td style="text-align: center;">_____</td> <td style="text-align: center;">_____</td> </tr> <tr> <td style="text-align: center;">_____</td> <td>d. Visible</td> <td style="text-align: center;">_____</td> <td style="text-align: center;">_____</td> </tr> <tr> <td style="text-align: center;">_____</td> <td>e. Gamma</td> <td style="text-align: center;">_____</td> <td style="text-align: center;">_____</td> </tr> <tr> <td style="text-align: center;">_____</td> <td>f. X-Radiation</td> <td style="text-align: center;">_____</td> <td style="text-align: center;">_____</td> </tr> </tbody> </table> <p>3. Describe the primary difference between ionizing and nonionizing radiation.</p> <p>_____</p> <p>_____</p> <p>_____</p> <p>4. List a source and biological effect for each of the following types of radiation.</p> <table style="width: 100%; border-collapse: collapse; margin-top: 10px;"> <thead> <tr> <th style="width: 30%;"></th> <th style="text-align: center; width: 30%;">Source</th> <th style="text-align: center; width: 40%;">Biological Effect</th> </tr> </thead> <tbody> <tr> <td style="vertical-align: top;">a. Ultraviolet</td> <td>_____</td> <td>_____</td> </tr> <tr> <td></td> <td>_____</td> <td>_____</td> </tr> <tr> <td style="vertical-align: top;">b. Infrared</td> <td>_____</td> <td>_____</td> </tr> <tr> <td style="vertical-align: top;">c. Radio Frequency</td> <td>_____</td> <td>_____</td> </tr> <tr> <td></td> <td>_____</td> <td>_____</td> </tr> </tbody> </table>		Rank	Region	Ionizing	Nonionizing	_____	a. Ultraviolet	_____	_____	_____	b. Radio frequency	_____	_____	_____	c. Infrared	_____	_____	_____	d. Visible	_____	_____	_____	e. Gamma	_____	_____	_____	f. X-Radiation	_____	_____		Source	Biological Effect	a. Ultraviolet	_____	_____		_____	_____	b. Infrared	_____	_____	c. Radio Frequency	_____	_____		_____	_____
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Self-Test	
Nonionizing and Ionizing Radiation	Module 6
<p>5. Describe the operation of a klystron unit. (Draw a diagram.)</p>	

Self-Test	
Nonionizing and Ionizing Radiation	Module 6
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Self-Test	
Nonionizing and Ionizing Radiation	Module 6
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Self-Test																				
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V	<hr/>	<hr/>																		
<p>15. What is the difference between the "near" and "far" fields of radio frequency radiation?</p> <hr/> <hr/> <hr/>																				
<p>16. Calculate the radius of the "near" field for radio frequency radiation, given the area of the antenna is 100.5 cm² and the wavelength is 10.5 cm.</p>																				

Self-Test

Nonionizing and Ionizing Radiation

Module 6

17. List at least five (5) causes of potential radio frequency hazard.

18. List at least two (2) types of detectors used for measurement of nonionizing radiation, their use, and basic principle of operation.

19. Define the following terms:

- a. Atom

- b. Proton

- c. Neutron

- d. Electron

- e. Isotope

- f. Radioactive Decay

- g. Half-Life ($T_{1/2}$)

Self-Test					
Nonionizing and Ionizing Radiation					Module 6
20. Complete the following table:					
	Type of Radiation Particle/Photon	Charge +,-,0	Atomic Weight amu	Penetrating Capability	Source (Machine, Decay)
Alpha	_____	_____	_____	_____	_____
Beta	_____	_____	_____	_____	_____
Photon	_____	_____	_____	_____	_____
Negatron	_____	_____	_____	_____	_____
Gamma	_____	_____	_____	_____	_____
X-radiation	_____	_____	_____	_____	_____
Neutron	_____	_____	_____	_____	_____
21. Define each of the following units of measure:					
a. Curie _____					
b. Roentgen _____					
c. rad _____					
d. rem _____					
22. Calculate the dose equivalent for an alpha source with a reading of 150.0 μ rad at 10 cm, and the maximum exposure time which would not exceed 0.23 rems/week.					
23. Describe the difference between an internal and external radiation hazard. Give an example of each.					

Self-Test

Nonionizing and Ionizing Radiation

Module 6

24. List at least four (4) uses of ionizing radiation in the industrial setting.

25. List at least three (3) hazards associated with radiation use.

26. Describe the principle of operation of the G-M counter and the characteristic difference between the G-M counter, proportional counter, and ionization chamber.

27. Describe the principles of operation of the

a. Scintillation detector _____

b. Photographic device _____

c. Thermoluminescent device _____

28. What is the primary difference between a pocket dosimeter and pocket ion chamber?

Self-Test

Nonionizing and Ionizing Radiation

Module 6

29. Describe the purpose of shielding and an example of an appropriate shielding material for each type of ionizing radiation.

30. Briefly describe the steps which can be taken to control

- a. Alpha _____
b. Beta _____
c. Gamma _____

31. Describe the procedure necessary to analyze

- a. Surface contamination _____
b. Air contamination _____
c. Water contamination _____

32. List five (5) potential design problems which may exist in a facility using radiation.

Self-Test

Nonionizing and Ionizing Radiation

Module 6

33. What steps should be taken if a person has been splashed with a solution containing a gamma/beta emitter?

Self-Test (Answers)

Nonionizing and Ionizing Radiation

Module 6

1. Define the following terms:

a. Photon Quantum of energy

b. Wavelength Distance from peak to peak of a wave

c. Frequency Number of vibrations/cycles per unit time.

2. Rank the following regions of the electromagnetic spectrum from highest to lowest frequency and indicate whether they are a form of ionizing or nonionizing radiation.

Rank	Region	Ionizing	Nonionizing
<u>3</u>	a. Ultraviolet	<u> </u>	<u>x</u>
<u>6</u>	b. Radio Frequency	<u> </u>	<u>x</u>
<u>5</u>	c. Infrared	<u> </u>	<u>x</u>
<u>4</u>	d. Visible	<u> </u>	<u>x</u>
<u>1</u>	e. Gamma	<u>x</u>	<u> </u>
<u>2</u>	f. X-Radiation	<u>x</u>	<u> </u>

3. Describe the primary difference between ionizing and nonionizing radiation.

Ionizing radiation has an energy level high enough to cause removal of electrons from atoms of absorbing materials; whereas, nonionizing radiation may cause electron excitation but cannot cause electron ejection.

4. List a source and biological effect for each of the following types of radiation.

	Source	Biological Effect
a. Ultraviolet	<u>Sun</u>	<u>Erythema</u>
	<u>Welding operation</u>	<u>Conjunctivitis</u>
		<u>Keratitis</u>
b. Infrared	<u>Molten material</u>	<u>General heating</u>
c. Radio Frequency	<u>Telecommunication</u>	<u>General heating</u>
	<u>Instruments</u>	

Self-Test (Answers)	
Nonionizing and Ionizing Radiation	Module 6
<p>5. Describe the operation of a klystron unit. (Draw a diagram.)</p> <p><i>The operation of a klystron is relatively simple. A stream of high speed electrons is produced at the cathode. The electrons travel towards the anode; and as they pass through the accelerating grid, they increase their speed. In the buncher cavity, the electrons are modulated by a microwave field into bunches. When the bunched electrons pass the catcher grid, the electrons slow down and microwave radiation is released and the microwaves are removed by the coaxial cable. Finally, the electrons are captured at the anode. The specific radiation released is dependent upon the dimensions of the tube, the dimensions of the cavity, and the velocity of the electrons.</i></p> <p><i>For diagram, see Figure 6.1.6 in textbook.</i></p>	

Self-Test (Answers)	
Nonionizing and Ionizing Radiation	Module 6
<p>6. Describe the operation of a typical laser unit. (Draw a diagram.) Describe the potential hazards of a laser unit.</p> <p><i>As an example, the ruby laser is discussed.</i></p> <p><i>The ruby laser is excited by optical pumping which lifts the system from the ground state of the chromium ion to one of the wide adsorption bands. These absorption bands are optically wide in comparison to the sharp photon wavelength later emitted.</i></p> <p><i>Once the absorption bands are excited, they quickly drop to a lower energy level by a radiationless transition. This lower energy level is actually split into two levels which are close together in energy. One of them is very long lived with a life of $T = 3$ milliseconds. One photon can be emitted by each state. The longer wavelength photon, which comes from the long-lived state, is more numerous. It is these photons which are emitted in a rapid pulse much shorter than the lifetime of the state which gives the high power of the ruby laser.</i></p> <p><i>The ends of the ruby crystal act as the optical cavity. Once the critical level is reached, the presence of photons stimulates emission of other photons, and chromium ions return to their ground state again. Simultaneous emission of the photons forms the coherent light. This light is then transmitted through the transmissive mirror-like end of the ruby crystal tube. The entire sequence described requires approximately one-thousandth of a second. The coherent wave is produced because the critical level of photons required for stimulated emission is reached.</i></p> <p><i>For diagram, see Figure 6.1.7 in textbook.</i></p>	

Self-Test (Answers)

Nonionizing and Ionizing Radiation

Module 6

7. What is the power density (W/cm^2) of a laser unit with
- power output--0.5 Joules
 - pulse length-- 10^{-4} seconds
 - focal size-- 0.5 mm^2

$$\text{power density} = 5.0 \times \frac{1}{10^{-4}} \times \frac{1}{.05 \times 10^{-2}} = \frac{10^{-6} W}{cm^2}$$

8. List at least three (3) hazards associated with ultraviolet radiation.

1. Direct exposure--erythema

2. Ozone production

3. Carcinogenic catalyst

4. Vitreous humor fluorescences

5. Decomposition of chlorinated hydrocarbons.

9. What is it necessary for ultraviolet measurements to approximate the actinic curve?

Specific wavelengths of UV spectrum have a relative effectiveness with respect to affecting man (e.g., erythema causing). Measurements should reflect and weight exposure according to the effect on man (actinic curve).

10. Describe the procedure used to determine the effective irradiance of an ultraviolet wide band source.

1. Narrow band measurements taken

2. Calculate E_{eff} using formula $E_{eff} = \sum E_{\lambda} S_{\lambda} \Delta \lambda$

3. Compare to TLV levels

11. List three (3) factors which affect the accuracy of ultraviolet source measurement.

1. Instrument must match spectral range of UV source.

2. Water vapor in atmosphere.

3. Solarization or aging of lens

4. Directionality of meters and probes

12. Briefly describe the effect of time and distance upon exposure to electromagnetic radiation.

Time--Exposure directly related to time of exposure; as time decreases, exposure decreases.

Distance--"Inverse square law"

Self-Test (Answers)

Nonionizing and Ionizing Radiation

Module 6

13. What is the beam intensity of a laser at 135 cm with

- a. power output--0.5 watts
- b. beam divergence--0.80 milliradians
- c. beam diameter--2.0 cm

$$I = \frac{E}{[(\pi/4)(a + \phi)]^2} = \frac{0.5 \text{ W}}{[(\pi/4)(2.0 + 135(8.0 \times 10^{-4}))]^2}$$

$$= 0.18 \text{ W/cm}^2$$

14. For each class of laser, describe the criteria for classification and at least one example of an operational requirement.

Class	Criteria	Operational Requirement
I	<u>Incapable of producing injury</u>	<u>None</u>
II	<u>May be viewed directly for short periods</u>	<u>Control beam direction</u> <u>Posting signs</u>
III	<u>Cannot be viewed directly</u>	<u>Eye protection</u> <u>Controlled area</u>
IV	<u>Cannot be viewed directly or exposure to reflected beam</u>	<u>Restricted area; fail safe system</u>
V	<u>Class II, III, IV encased to prevent emission of hazardous radiation.</u>	<u>Laser encasement</u>

15. What is the difference between the "near" and "far" fields of radio frequency radiation?

The "near" field has energy carried by magnetic and electric vector and may reflect interference of source with waves. "Far" field is primary an electric vector.

16. Calculate the radius of the "near" field for radio frequency radiation, given the area of the antenna is 100.5 cm² and the wavelength is 10.5 cm.

$$r = \frac{A}{2\lambda}$$

$$r = \frac{100.5 \text{ cm}^2}{2(10.5 \text{ cm})} = 4.786$$

Self-Test (Answers)

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17. List at least five (5) causes of potential radio frequency hazard.

1. Improper installation--Poor location, inadequate shielding
2. Unauthorized operating personnel
3. Ignoring operating defects; failing interlocks
4. Lack of personnel attention to operation
5. Poor maintenance schedule
6. Poor engineering design

18. List at least two (2) types of detectors used for measurement of nonionizing radiation, their use, and basic principle of operation.

1. Thermopile--UV radiation monitoring, absorption of UV radiation causes increase in temperature and increase in voltage production.
2. Photon devices--e.g., laser beam measure; absorption of photons converted to voltage difference, current, etc.

19. Define the following terms:

- a. Atom Smallest particle of an element which possesses the chemical properties of that element.
- b. Proton Particle which is found in nucleus; has a charge of +1 and a mass of 1 amu; determines chemical property of atom.
- c. Neutron Particle found in nucleus; has no charge and a mass of 1 amu.
- d. Electron Particle found outside nucleus of an atom; has -1 charge and a mass of 5.34×10^{-4} amu.
- e. Isotope Atoms with same number of protons but different number of neutrons.
- f. Radioactive Decay Spontaneous transformation of atom to reach lower, more stable energy level.
- g. Half-Life ($T_{1/2}$) Time required for 0.5 of isotopes present to decay to a new element.

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20. Complete the following table:

	Type of Radiation Particle/Photon	Charge +,-,0	Atomic Weight amu	Penetrating Capability	Source (Machine, Decay)
Alpha	<u>Particle</u>	<u>+2</u>	<u>4</u>	<u>Very small</u>	<u>Decay</u>
Beta	<u>Particle</u>	<u>+1</u>	<u>0</u>	<u>Medium</u>	<u>Decay</u>
Photon	<u>Particle</u>	<u>-1</u>	<u>0</u>	<u>Medium</u>	<u>Decay</u>
Negatron	<u>Photon</u>	<u>0</u>	<u>0</u>	<u>Deep</u>	<u>Decay</u>
Gamma	<u>Photon</u>	<u>0</u>	<u>0</u>	<u>Deep</u>	<u>Machine</u>
X-Radiation	<u>Particle</u>	<u>0</u>	<u>1</u>	<u>Medium</u>	<u>Fission</u>
Neutron					

21. Define each of the following units of measure:

- Curie Unit of activity; 3.7×10^{10} disintegration/second
- Roentgen Unit of exposure for X- and gamma radiation
- rad Unit of absorbed dose
- rem Unit of dose equivalent = $QF \times \text{rad (R)}$; takes into consideration various biological effectiveness

22. Calculate the dose equivalent for an alpha source with a reading of 150.0 μ rads at 10 cm, and the maximum exposure time which would not exceed 0.23 rems/week.

$$\begin{aligned}
 \text{rem} &= 20 \times 150.0 \times 10^{-6} \text{ rads} \\
 &= 30 \times 10^{-4} \text{ rems} \\
 \text{time} &= \frac{30 \times 10^{-4} \text{ rems}}{0.23 \text{ rems}/40 \text{ hours}} = 0.52 \text{ hours or } 31.2 \text{ minutes}
 \end{aligned}$$

23. Describe the difference between an internal and external radiation hazard. Give an example of each.

- Internal--hazard which is being emitted from within body; e.g., alpha emitter absorbed through respiratory tract.
- External--hazard which penetrates the skin; e.g., gamma radiation

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24. List at least four (4) uses of ionizing radiation in the industrial setting.

- | | |
|-------------------------------|---|
| <u>1. radioactive tracers</u> | <u>4. radiographic analysis (X-ray)</u> |
| <u>2. radiation gauges</u> | <u>5. electron beam equipment</u> |
| <u>3. luminescent dials</u> | <u>6. activation analysis</u> |

25. List at least three (3) hazards associated with radiation use.

1. Direct exposure
2. High voltages of associated equipment
3. Presence of toxic substance formed because of radiation

26. Describe the principle of operation of the G-M counter and the characteristic difference between the G-M counter, proportional counter, and ionization chamber.

Ionizing radiation falls on chamber; ions formed in chamber from radiation, high voltage causes avalanche of ionization of all atoms in chamber; sequence registered on meter.

Difference: Meter reading not proportional to radiation present.

27. Describe the principles of operation of the

- a. Scintillation detector Radiation interacts with phosphor causing production of light; light production measured with photomultiplier.
- b. Photographic device Film sensitive to various types of radiation; developed exposure proportional to radiation present.
- c. Thermoluminescent device Crystalline material exposed to radiation; causing "holes" in lattice structure; material then heated; electrons recombine and light is emitted; quantity of light emitted proportional to radiation present.

28. What is the primary difference between a pocket dosimeter and pocket ion chamber?

The pocket chamber requires a separate unit to be read; the pocket dosimeter does not.

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<p>29. Describe the purpose of shielding and an example of an appropriate shielding material for each type of ionizing radiation.</p> <p><i>Shielding absorbs the radiation and reduces the exposure; e.g.,</i></p> <p><i>Alpha--any airtight enclosure</i></p> <p><i>Beta--aluminum</i></p> <p><i>Gamma--lead</i></p> <p><i>Neutron--water</i></p>	
<p>30. Briefly describe the steps which can be taken to control</p> <p>a. Alpha <i>Enclosure--glove box</i></p> <p>b. Beta <i>Glove box, shielding, distance, decrease exposure time.</i></p> <p>c. Gamma <i>Shielding, distance, decrease exposure time.</i></p>	
<p>31. Describe the procedure necessary to analyze</p> <p>a. Surface contamination <i>Smear test</i></p> <p>b. Air Contamination <i>Air sampling along with calculation of contaminant concentration</i></p> <p>c. Water contamination <i>Water sampling along with calculation of contaminant concentration</i></p>	
<p>32. List five (5) potential design problems which may exist in a facility using radiation.</p> <p><i>1. Porous surfaces</i></p> <p><i>2. Dust collecting areas</i></p> <p><i>3. Leakage around shielding</i></p> <p><i>4. Hood design problems</i></p> <p><i>5. Inadequate drainage systems for liquids</i></p>	

Self-Test (Answers)

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33. What steps should be taken if a person has been splashed with a solution containing a gamma/beta emitter?

If personnel contamination is suspected, first identify the contaminated areas with survey meter. Do not use decontamination methods which will spread localized material or increase penetration of the contaminant into the body (e.g., by abrasion of the skin). Decontamination of wounds should be accomplished under the supervision of a physician.

Irrigate any wounds profusely with tepid water and clean with a swab. Follow with soap or detergent and water (and gentle scrubbing with a soft brush, if needed). Avoid the use of highly alkaline soaps (may result in fixation of the contaminant) or organic solvents (may increase skin penetration by contaminant).

Use the following procedures on intact skin:

- a. Wet hands and apply detergent.*
- b. Work up good lather, keep lather wet.*
- c. Work lather into contaminated area by scrubbing gently for at least 3 minutes. Apply water frequently.*
- d. Rinse thoroughly with lukewarm water (limiting water to contaminated areas).*
- e. Repeat above procedures several times, gently scrubbing residual contaminated areas with soft brush, if necessary.*
- f. If the radiation level is still excessive, initiate more powerful decontamination procedures after consultation with the radiation protection office.*

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